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Environment Canada
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Special announcement

To conform with Canada's policy on Bilingualism we have translated the Journal's title into French, beginning with this issue, Volume 32, No. 1, 1975.

Indexers, abstracters, and librarians should note that the standard title abbreviation remains as *J. Fish. Res. Board Can.* To minimize problems in documentation and retrieval that might result from the *Journal* having two titles the standard title abbreviation is shown on the spine, is repeated on every verso page, and in the bibliographic strip located above each language version of the abstracts.

Avis spécial

Conformément à la politique canadienne sur le bilinguisme, le titre du *Journal* sera traduit en français à partir de la présente publication, volume 32, n° 1, 1975.

Indexateurs, analystes de documents et bibliothécaires sont priés de noter que l'abréviation du titre, *J. Fish. Res. Board Can.*, demeurera inchangée. Pour réduire les problèmes de documentation et de recherche qui pourraient résulter de l'usage de deux titres, l'abréviation du titre figure au dos, est répétée à chaque page paire et paraît dans la référence bibliographique qui précède les deux versions des résumés.

Journal of the Fisheries Research Board of Canada

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Temperature-Induced Changes in Acute Toxicity of Zinc to Atlantic Salmon (*Salmo salar*)[1]

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HODSON, P. V., AND J. B. SPRAGUE. 1975. Temperature-induced changes in acute toxicity of zinc to Atlantic salmon (*Salmo salar*). J. Fish. Res. Board Can. 32: 1–10.

Three groups of Atlantic salmon (*Salmo salar*) parr were acclimated to water temperatures of 3, 11, and 19 C. When exposed at their acclimation temperature to lethal concentrations of zinc, cold-acclimated salmon survived longer than warm-acclimated salmon. However, the threshold lethal concentration (LC50) of zinc was highest for salmon at 19 C, i.e. there was less toxicity at the high temperature. At test temperatures lower than prior acclimation temperatures, survival times in zinc were longer but the threshold LC50 was lower, i.e. fish were less tolerant of zinc. The opposite results were seen at temperatures above prior acclimation temperatures.

The threshold LC50 may be predicted by the equation $LC50 = 1.9611 - 0.1873\ Ta + 0.8699\ Te - 0.0414\ Te^2 + 0.00004\ Ta\ Te^3$, where Ta = temperature of acclimation and Te = temperature of exposure.

In polluted rivers, zinc concentrations may be most damaging to fish populations during the winter months. Measured concentrations of zinc and copper in the Miramichi River, New Brunswick were highest in winter when estimated toxicity of metal was also greatest.

HODSON, P. V., AND J. B. SPRAGUE. 1975. Temperature-induced changes in acute toxicity of zinc to Atlantic salmon (*Salmo salar*). J. Fish. Res. Board Can. 32: 1–10.

Trois groupes de tacons de saumon atlantique (*Salmo salar*) ont été acclimatés à des températures de l'eau de 3, 11 et 19 C. Lorsque exposés, à leur température d'acclimatation, à des concentrations létales de zinc, les saumons acclimatés au froid survivent plus longtemps que les saumons acclimatés à la chaleur. Cependant, la concentration létale de seuil (CL50) de zinc est plus élevée pour les saumons à 19 C, i.e. la toxicité est moins forte à la température élevée. A des températures d'essai plus basses que les températures d'acclimatation précédente, les périodes de survie dans le zinc sont plus longues, mais la CL50 de seuil est plus basse, i.e. les poissons sont

[1]Based on a thesis by P. V. Hodson submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the Department of Zoology, University of Guelph, 1974.

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moins tolérants au zinc. On observe des résultats opposés, à des températures supérieures aux températures d'acclimatation précédente.

Il est possible de prédire la CL50 de seuil à l'aide de l'équation CL50 = 1.9611–0.1873 Ta + 0.8699 Te–0.0414 Te^2 + 0.00004 Ta Te^3, dans laquelle Ta = température d'acclimatation et Te = température d'exposition.

Dans les rivières polluées, les concentrations de zinc peuvent causer le plus de dommage aux populations de poissons durant les mois d'hiver. Les concentrations de zinc et de cuivre mesurées dans la rivière Miramichi, Nouveau-Brunswick, sont maximales en hiver, alors que la toxicité estimée du métal est également à son maximum.

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To protect aquatic ecosystems from heavy metals, water quality criteria have been developed from controlled laboratory bioassays. However, the toxicity of heavy metals varies with physical and chemical characteristics of the receiving water, as has been pointed out in several reviews (Skidmore 1964; Sprague 1970).

Temperature is one important characteristic that could affect metal toxicity, since most aquatic organisms are poikilothermic. In Canada, there are large temperature differences with season and latitude. For example, Char Lake in the North West Territories is less than 1.0 C for 9 mo of the year (Roff and Carter 1972). In contrast, the Grand River in Southern Ontario is between 20 and 27 C for up to 4 mo of the year (Chang-Kue 1972). Consequently, Canada's water quality criteria should consider the interaction of toxicity with temperature.

The purpose of this experiment was to determine how the temperatures of acclimation and exposure affect the acute toxicity of a metal to fish.

Materials and Methods

Atlantic salmon (*Salmo salar*) was chosen as the test species since base metal mining in Northeastern New Brunswick has affected salmon stocks of economic importance (Montreal Engineering 1972, 1973). Zinc was chosen as a representative metal toxicant. It constituted about 60% of the total mineral production of New Brunswick in 1972 (Mineral Resources Branch 1973) and it has occurred in concentrations close to the lethal level in New Brunswick waters (Saunders and Sprague 1967; Sprague and Carson 1964). Zinc was added to water as $ZnSO_4 \cdot 7H_2O$ but all concentrations refer to the ionic form Zn^{++}.

Water temperatures in Maritime salmon rivers range from 0 C during the winter to summer afternoon peaks of 28.8 C (Sprague and Carson 1964). Within this range, temperatures from 3 to 19 C were tested because preliminary bioassays indicated that a sudden change of 16 C was the maximum that did not kill salmon. Test temperatures that were higher or lower than acclimation temperatures will be referred to as heat and cold stresses, respectively.

The toxic response measured was lethality, i.e. whether the exposed fish lived or died. Median effective times (ET50) for mortality of salmon were measured at six concentrations of zinc in a 3 × 3 design of 3, 11, and 19 C for both acclimation and test temperatures. Subsequently, a 2-wk median lethal concentration of zinc (LC50) was calculated for each of the nine temperature combinations. Since all mortality occurred in less than 1 wk, the 2-wk LC50s estimated the threshold LC50s. Threshold resistance levels will measure tolerance as defined by Fry (1947). For example, fish would show less tolerance if the threshold LC50 were lowered, i.e. the zinc were more toxic. When thresholds were poorly defined, 28-day bioassays were conducted at additional concentrations close to the estimated thresholds.

Fish and Acclimation Conditions

Atlantic salmon were obtained in June, 1971 from the Craig Brook National Hatchery at East Orland, Maine. They had been hatched in March, 1971 from eggs of Penobscot River salmon.

At the University of Guelph, fish were held in cylindrical fiberglass tanks, 1.2 m in diameter, with 345 fish/tank. Water depth was 18.5 cm, volume was about 110 liters, and flow rate was 3–4 liter/minute of aerated well water. The 95% replacement time was 1.5–2 h. The well water was very hard, alkaline, low in suspended solids, and these parameters were relatively constant (Tables 1 and 2). Oxygen concentrations were 80% of air saturation or greater and were usually above 6.0 mg/liter.

Zinc concentrations in the well water ranged from "not detectable" to 0.19 mg/liter in initial sampling (Table 1). Consequently, zinc content of water in the acclimation tanks was measured weekly from April 3 to June 19, 1972, using atomic absorption spectrophotometry, a reference solution prepared by Fisher Scientific Co., and acidified samples. Measurements ranged from "not detectable" to 0.26 mg/liter with a mean and 95% confidence limits of 0.05 ± 0.04 mg/liter.

Fish were acclimated to 3, 11, or 19 C. Change from an initial 10 C was spread over 20 days. Final acclimation temperatures were maintained for at least 23 days before bioassays were started and they fluctuated only slightly (Table 2). The photoperiod for

TABLE 1. Chemical characteristics of the well water used for all experiments.[a] All units are milligrams/liter unless noted otherwise. nd = not detectable.

Date	Dec. 11, 1970	Sept. 1, 1971	Oct. 4, 1971
Copper	nd		<0.06
Nickel	nd		
Zinc	0.19	nd	0.04
Cadmium	nd		
Iron	0.11	0.10	0.05
Lead	nd		
Chloride			18
Phenols			nd
Free ammonia as N		0.03	0.01
Nitrate as N		0.07	
Nitrite as N		0.005	
Phosphorous as P — total		0.006	
— soluble		0.001	
Hardness as $CaCO_3$		352	354
Alkalinity as $CaCO_3$		228	226
Acidity as $CaCO_3$		15	
Conductivity (μmhos/cm^3)		556	
Suspended solids			<5
Hydrogen-ion concentration (pH)		7.6	7.2

[a]Determined by the Chemistry Branch, Ontario Water Resources Commission.

acclimation and testing was 16 h of incandescent light and 8 h of darkness.

Fish were fed once each Monday, Wednesday, and Friday with a mixture of ground beef liver and gelatine. Fish size varied with water temperature. Over 3 mo, fish at 3 C ate only enough to maintain their weights at about 1 g, while those at 11 and 19 C grew continuously (Table 2). Size variation was not considered important since control bioassays indicated that a 6.5 fold difference in weight did not affect survival-time in zinc.

EXPERIMENTAL PROCEDURE

Continuous-flow bioassays were used. Each of six fail-safe toxicant meters (Hodson 1974) delivered 1 liter/minute of zinc-treated water. This was divided among three plastic tanks for a total of 18 exposure tanks. Six tanks were maintained at each of the three temperatures by insulation or water baths. Each exposure tank contained 18 liters of continuously aerated water and received a flow of 0.33 liters/minute. This gave a 95% replacement time of 2.5 h and a minimum of 6 liters of water/gram of fish per day.

Each exposure was characterized by the average measured concentration of zinc, from daily or more frequent sampling. Mean measured concentrations deviated from nominal concentrations by less than 10%, and 95% confidence intervals were within 10% of the mean measured concentration, except in one case (details in Hodson 1974). At the experimental pH's of 7.6–8.0 and mean hardness of 366 mg/liter, the theoretical limit of solubility of zinc was estimated as 0.5–4.0 mg/liter (O'Connor and Schmidt 1965). Consequently, some of the zinc in our bioassays may not have been in solution. However, Hem (1972) considers a working definition of dissolved solids as those not retained by a 0.45-μ filter, and this criterion is confirmed by empirical observations on toxicity of metals to fish (C. E. Stephen, U.S.E.P.A., personal communication). Accordingly, two samples of our bioassay water were passed through a 0.45-μ filter before acidification. The unfiltered samples contained 24.8 and 1.04 mg/liter zinc while the filtered samples contained 22.7 and 1.02 mg/liter. The differences were 8.5 and 3.5%, respectively, and could represent absorption to the filter material. Because of this and the lack of obvious precipitate, all zinc was considered dissolved.

Ten salmon were randomly selected and placed in each bioassay tank. Observations of mortality were made at logarithmically increasing intervals up to 3 days, then at least 3 times daily. Maximum possible error on any individual mortality-time was below 10%. Fish were considered dead when opercular movements ceased for 2 min and there was no response to handling.

ET50s, threshold LC50s, and their 95% confidence intervals were calculated by probit analysis (Finney 1964) adapted to APL 360 by Prof R. J. Douglas and C. W. Ross, University of Guelph. Multiple regression analyses determined the relationships between (a) ET50s and measured zinc concentrations and (b) threshold LC50s, acclimation temperatures, and exposure temperatures. Significance of the slopes and regressions was tested at the 90% confidence

TABLE 2. Fish sizes and chemical characteristics of water in acclimation tanks. Means and 95% confidence limits (sample size).

Tank:	2	4	3
Temp[a] (*C*)	2.8±0.10(114)	10.9±0.03(114)	18.9±0.09(114)
Oxygen[b] (*mg/liter*)	11.0±3.5(15)	9.0±0.23(15)	6.9±0.44(15)
Avg % saturation	86	101	80
Hardness[c] (*mg/liter*)			366 ±30.3(32)
pH (*range*)			7.6–8.0(10)
	Fish length (cm)		
Oct., 1971	4.9±0.12(29)	6.1±0.17(29)	6.0±0.16(30)
Nov., 1971	5.0±0.10(57)	6.7±0.16(81)	6.2±0.29(84)
Jan., 1972	4.8±0.21(14)	8.5±0.33(12)	
	Fish wt (g)		
Oct., 1971	1.1±0.08(29)	2.1±0.23(29)	2.2±0.19(30)
Nov., 1971	1.1±0.07(57)	3.1±0.26(81)	3.0±0.18(84)
Jan., 1972	1.1±0.19(14)	6.2±0.78(12)	
Age (*mo*)	7–10	7–10	7–10

[a]Measured daily.
[b]As determined weekly by the Azide modification to the Winkler method (A.P.H.A. et al. 1971).
[c]As determined weekly by the methods of the Hach Chemical Corporation.

level since there were relatively few dependent variables in each analysis.

Results

Figure 1 shows the relationship between acclimation and exposure temperatures and the thresholds of zinc lethality. The formula in the legend describes the "best-fit" plane as calculated by a multiple regression computer program (details in Hodson 1974). The measured LC50s with 90% confidence intervals indicate that the equation gives a good description of the data. This was confirmed by a multiple coefficient of determination (R^2) of 85.2% (i.e. 85.2% of the variation in lethal thresholds results from variation in temperatures). Salmon acclimated and exposed at a water temperature of 19 C were more tolerant of zinc than were those acclimated and exposed at 3 and 11 C. Heat stresses of 8 C resulted in more tolerance of zinc by salmon acclimated to 3 and 11 C. A 16 C heat stress did not affect tolerance of zinc by salmon acclimated to 3 C. All cold stresses resulted in less tolerance of zinc by salmon acclimated to 11 and 19 C.

Figure 2A shows the ET50s at various zinc concentrations when there was no temperature stress. The "best-fit" lines closely followed the individual observations and slopes were similar for the three lines. Lower acclimation tempera-

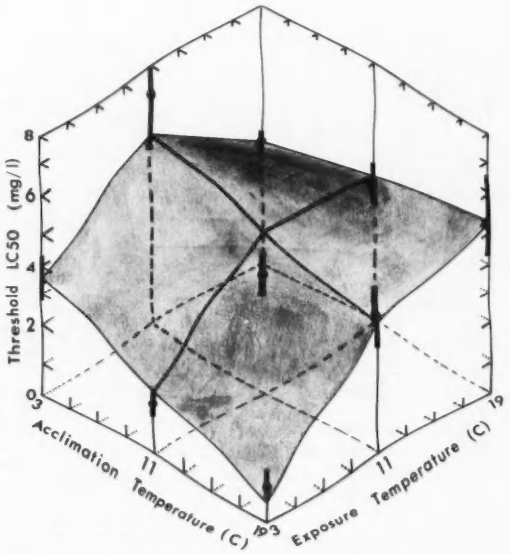

FIG. 1. Variation of lethal thresholds of zinc with acclimation and exposure temperature. Threshold LC50 = 1.9611–0.1873 Ta + 0.8699 Te–0.0414 Te^2 + 0.00004 $TaTe^3$. Where Ta = acclimation temperature, Te = exposure temperature, ◆ = measured thresholds, with 90% confidence intervals.

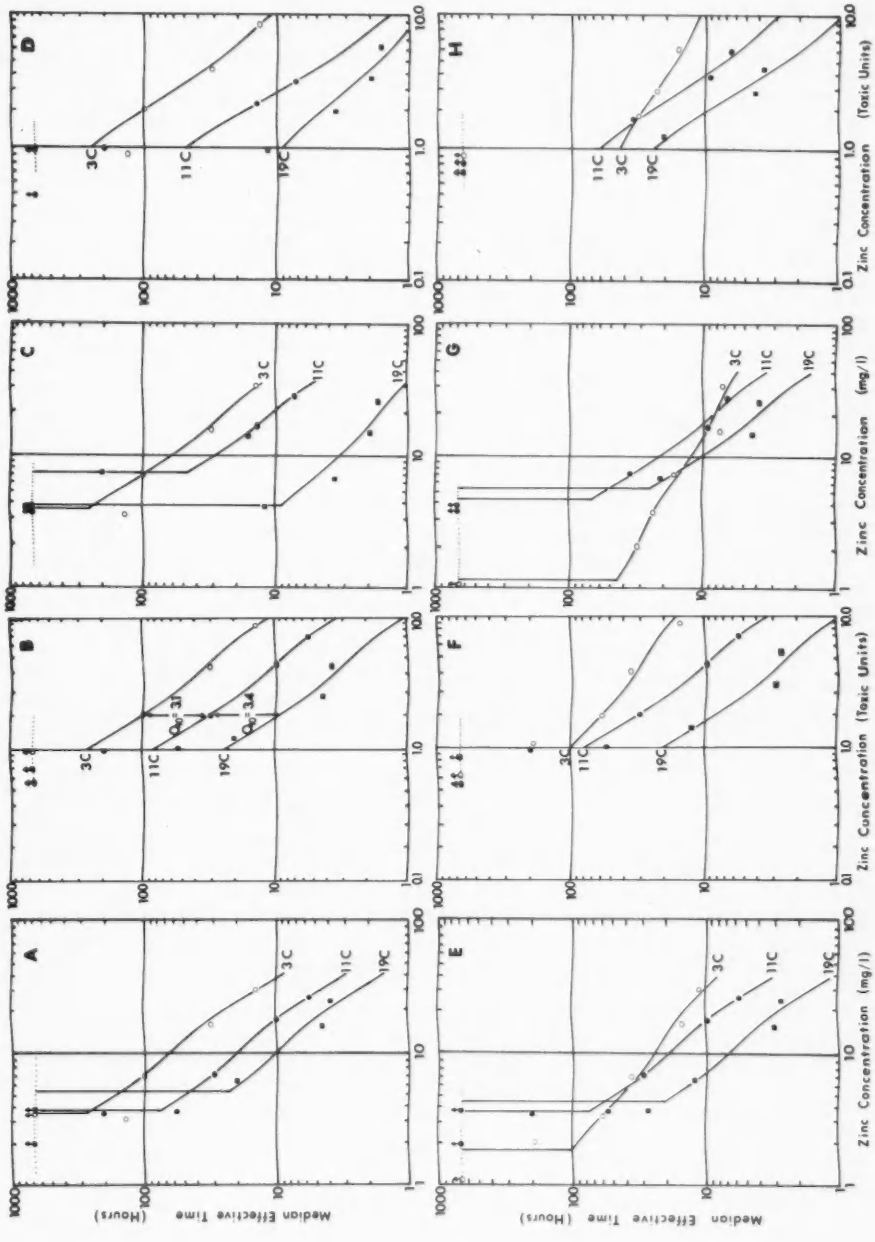

FIG. 2. Mortality times of Atlantic salmon (*Salmo salar*) exposed to zinc at 3, 11, and 19 C: A, B — when acclimation temperatures equalled exposure temperatures; C, D — when acclimation temperature was 3 C; E, F — when acclimation temperature was 11 C; and G, H — when acclimation temperature was 19 C. "Best-fit" lines were fitted to data points by equations given by Hodson (1974). However, one equation describes the relationship of toxic units to ET50s at all three temperatures in B. This equation is:

$$ET50 = \text{antilog}\,(2.6018 - .0647\,Ta - 1.3768\,Tu)$$

$R^2 = 98.43\%$; Ta = acclimation temperature; Tu = toxic units.

tures were associated with longer survival but less tolerance, i.e. lower LC50s. To construct Fig. 2B, zinc exposures were equalized by considering all threshold lethal concentrations equal to 1.0 toxic unit. Concentrations above threshold were expressed as multiples of toxic units. All three regression lines were described by one equation. For equal toxic units, the Q_{10} for change in mortality rate (the inverse of ET50) was 3.13–3.37.

Salmon acclimated to 3 C had shorter survival when exposed to a heat stress (Fig. 2C, D). Heat stress also caused slight decrease in the slope of the toxicity curve.

Salmon acclimated to 11 C (Fig. 2E, F) survived longer with an 8 C cold stress but died faster with an 8 C heat stress. The cold stress decreased the slope of the toxicity curve.

Salmon acclimated to 19 C (Fig. 2G, H) survived longer with 8 and 16 C cold stresses. However, the 16 C cold stress caused a large decrease in the slope of the toxicity curve.

In summary, salmon exposed to lethal concentrations of zinc at their acclimation temperature (no temperature stress) survived longer at lower acclimation temperatures. However, salmon were less tolerant (i.e. lower LC50s) as acclimation temperatures became lower. Moderate (8 C) and severe (16 C) heat stresses shortened time to mortality and either increased (8 C) or caused no change (16 C) in tolerance. Severe heat stresses also changed the pattern of response by altering the slope of the toxicity curves. Moderate (8 C) and severe (16 C) cold stresses lengthened time to mortality similarly, but decreased tolerance. Cold stresses decreased the slopes of the toxicity curves.

Discussion

The results of this experiment clearly indicate that water temperature alters the toxicity of zinc to Atlantic salmon. Temperature-acclimated fish were about 50% more tolerant of zinc at 19 C than at 3 C for acclimated fish. Sudden temperature changes altered thresholds even more.

Salmon exposed to zinc at their acclimation temperatures had toxicity curves with the same slope. One model or equation described their reaction at three temperatures to a given number of toxic units of zinc. In this model, the rate of mortality (the inverse of median effective time) was a simple function of temperature with a Q_{10} of 3.13–3.37, i.e. a 10 C increase in acclimation temperature caused a 3.13–3.37 fold increase in the rate of mortality. Therefore, for fish exposed at their acclimation temperature it is possible that zinc toxicity is controlled by temperatures in a similar way that enzyme kinetics are controlled.

However, if temperature stress is present, there is no such simple kinetic effect. Slopes of toxicity curves change, and zinc toxicity appears to be enhanced by temperature as a stressor. Temperature may have produced this effect through transient changes in metabolic rate. Fish appear to accumulate zinc from the water primarily through the gills (Eisler 1967; Saiki and Mori 1955; Slater 1961). Uptake would be controlled by amount of zinc available and hence by amount of water passing over the gills. Slowing of metabolism due to cold (Heath 1973) may have induced longer survival by reducing ventilation rate and consequently zinc uptake. Similarly, metabolic acceleration due to heat may have shortened survival by accelerating zinc accumulation. The increase in ET50s was not proportionately as large for a 16 C cold stress as for an 8 C cold stress. Conversely, the decrease in ET50s for a 16 C heat stress was proportionately larger than for an 8 C stress. Therefore, the greater temperature stresses appear to have added to the toxicity of zinc.

Reduction in thresholds with cold stress and increase with heat stress may have resulted from slowing and speeding of a process aiding survival. This might be for example, some mechanism that removes Zn^{++} from the site of toxic action. Alternatively, the sensitivity to zinc poisoning of some biochemical process might vary with temperature. For example, isoenzymes active during a heat exposure might differ in sensitivity to zinc from those active during a cold exposure.

These results agree with those in the literature. Atlantic salmon temperature-acclimated in soft water survived longer in zinc concentrations at 5 C than those at 17 C (Sprague 1964). Bluegills (*Lepomis macrochirus*) also showed longer survival in zinc concentrations at lower acclimation temperatures (Burton et al. 1972; Cairns et al. 1971). The same result was observed with rainbow trout exposed to mercury (MacLeod and Pessah 1973) and zinc (Lloyd 1960). However, Lloyd did not find any change in threshold, perhaps because of inadequate 5-day acclimation. *Fundulus parvipinnis* and *Gillichthys mirabilis* survived longer in various anesthetics and cyanide when they were cold-acclimated (Sumner and Wells 1935).

When temperatures are changed during a bioassay, or less than 2 days prior to it, a temperature stress is probably included. Heat stresses shortened ET50s of: bluegills exposed to zinc (Burton et al. 1972); goldfish exposed to lithium

TABLE 3. Predicted[a] threshold LC50s compared to observed LC50s reported in the literature for salmonids in hard water. The first line is for Atlantic salmon (*Salmo salar*), the rest are for rainbow trout (*Salmo gairdneri*). Water hardness was 320 mg/liter in all cases, and pH was between 7.0 and 7.9.

Author	Temp	Type of LC50	Measured LC50 (mg/liter)	95% Limits (*mg/liter*)	Calculated[a] threshold LC50 (*mg/liter*)	Calculated / Measured (%)
Herbert and Wakeford (1964)	12.5–13.5	48-h	≃5	–	4.98	99.6
Ball (1967)	14.5–15.8	5-day	4.6	3.8–5.5	4.91	106.7
Brown and Dalton (1970)	15.3–18.4	48-h	4.0	3.63–4.46	4.91	122.6
Brown et al. (1969)	10–12	48-h	4.0	3.50–4.56	5.05	126.2
Herbert and Shurben (1963)	10–14	48-h	3.8	–	5.02	132.1
Herbert and Shurben (1964)	17.5	48-h	3.86	3.65–4.09	4.98	130.8
Lloyd (1960)	17.5	7-day	≃4	–	4.98	124.6
Lloyd (1961)	15.5–17.0	3-day	3.5	–	4.95	141.5

[a]Calculated on the basis of the present findings as follows: $LC50 = 1.9611–0.1873\ Ta + 0.8699\ Te–0.0414\ Te^2 + 0.00004\ TaTe^3$ where Ta = acclimation temperature, Te = exposure temperature.

or ammonium ions (Powers 1920); fiddler crabs exposed to cadmium (O'Hara 1973a and b) and sticklebacks exposed to ammonia at high salinities (Hazel et al. 1971). Temperature stresses did not affect ET50s of sticklebacks at low salinities or striped bass at any salinity when exposed to ammonia (Hazel et al. 1971). Brown et al. (1967) acclimated rainbow trout for only 48–60 h and found that ET50s in phenol solutions increased with increasing temperature. If phenol is metabolized by trout, increasing temperatures may have increased the rate of detoxification.

The equation from Fig. 1:

$$LC50 = 1.9611–0.1873\ Ta + 0.8699\ Te– 0.0414\ Te^2 + 0.00004\ Ta\ Te^3 \quad (1)$$

may be used to predict the lethal threshold of zinc for salmon in hard water, at temperatures of acclimation (Ta) and exposure (Te) between 3 and 19 C. Exposure temperature has a more than linear effect and interacts with acclimation temperature. It appears to act as an additional stressor or toxicant. The only major discrepancy between observed and predicted LC50s (Fig. 1) was for acclimation and experimental temperature of 11 C, when the prediction was 39% too high. An equation could be derived to fit this somewhat irregular response more closely, but additional terms would make it more cumbersome. The present simpler equation seems satisfactory; it will probably find its major use in situations with extreme temperatures or temperature stresses, for which toxicity is predicted quite accurately.

The equation predicts exactly the LC50 observed for salmon by Herbert and Wakeford (1964) (Table 3). This equation may also be used to predict LC50s for rainbow trout (*Salmo gairdneri*) with reasonable accuracy. Grande (1967) showed that the toxicity of zinc to rainbow trout and Atlantic salmon was similar under the same test conditions. A comparison of observed to predicted LC50s for rainbow trout (Table 3) indicates that the maximum difference between the two is 42% of the observed values, and the average is 26%. Considering the sensitivity of bioassay results to biological as well as physical factors (Kemp et al. 1971; Skidmore 1964; Sprague 1970), equation (1) gives a good approximation of observed values. Several of the observed temperatures are in the vicinity of 11 C, and predictions would be expected to be more accurate for all other temperature combinations. Other published values for zinc lethality to fish were not comparable due to major differences in kinds of fish or chemical characteristics of water.

The possible importance of these results was assessed by considering temperature, copper, and zinc in a polluted salmon river in New Brunswick during 1963 (Sprague and Carson 1964). Copper contributed 63% of the toxicity, on a yearly average. Both metal concentrations were converted to toxic units based on thresholds of lethality in water of the same hardness but uncorrected for

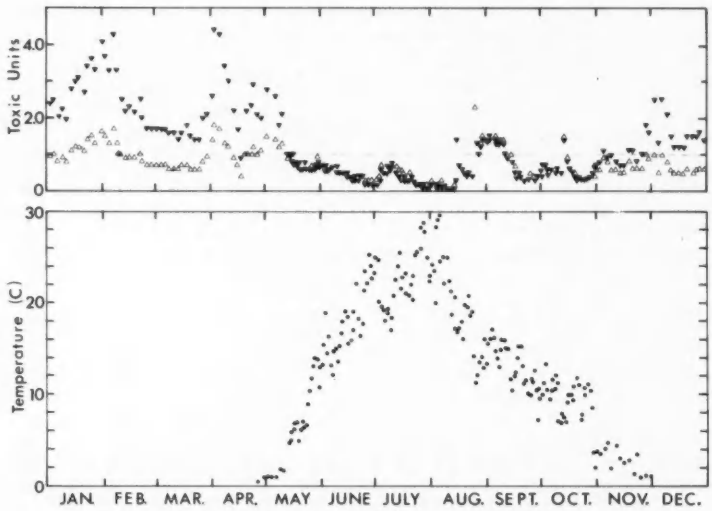

FIG. 3. Annual variation of water temperature and copper–zinc toxic units in the Northwest Miramichi River, N.B. during 1963. △ = toxic units based solely on metal concentrations; ▼ = toxic units corrected for temperature; - - - - - is one toxic unit, the threshold of lethality.

temperature (Sprague 1964). Figure 3 demonstrates how frequently the sum of these units approaches or exceeds 1.0, the threshold lethality. This is a good method for calculating the combined toxicity of copper and zinc at low concentrations (Brown 1968; Brown and Dalton 1970; Herbert and Shurben 1964; Lloyd 1961; Sprague 1964; Sprague 1970; Sprague and Ramsay 1965).

Figure 3 includes the same toxic units corrected for temperature according to equation (1). Acclimation temperature was taken as the mean of water temperatures recorded at 0900 and 1700 each day. Exposure temperature was chosen as the water temperature at 1700 to simulate a small temperature stress. The new lethal threshold was corrected for hardness by dividing by the ratio of the calculated threshold at 15 C in hard water to the measured threshold at 15 C in soft water (Sprague 1964). Toxic units were calculated with the new threshold as described.

The reduction of heavy metal toxicity by humic acids (Cook and Côte 1973; Wilson 1972; Zitko et al. 1972) was ignored for the sake of simplicity. In addition, the calculations assumed that: 1) the temperature–threshold relationship does not vary with hardness; 2) the temperature–threshold relationship is the same for both copper and zinc; 3) the model can be extended beyond the 3–19 C test range; 4) daily variations in pH, hardness, etc., would not greatly affect toxicity; and 5) salmon were acclimated to the daily mean stream temperature.

In the range of 4–20 C, the temperature-corrected toxic units differ little from the uncorrected ones (Fig. 3). Above 20 C corrected toxic units are slightly lower than noncorrected units, but below 4 C, they are considerably higher. If the corrected units are valid, extensive winter mortality would be expected among any salmon present. This is aggravated by lengthy periods during the winter months when copper and zinc concentrations are at their peak. Although salmon survive longer at low temperatures, they would not do so for more than a month.

The model predicting these thresholds may certainly be criticized for the simplifications of the basic assumptions. For example, the assumption of complete temperature acclimation is probably not valid. The work of Peterson and Anderson (1969) suggests that salmon and brook trout required about 2 wk for acclimation to temperature changes of 12 C. Consequently, acclimation of fish in the Miramichi River lagged considerably behind the temperature changes. Therefore, fish were probably experiencing large temperature stresses, especially during freshets, that would influence lethal thresholds.

Such environmental interaction is documented by Pippy and Hare (1969) who attribute summer mortality of fish in the Miramichi River to com-

bined high levels of temperature, metal pollution, and disease. There have been no reports of winter mortality of fish in New Brunswick rivers perhaps because of difficulties in detecting it.

While this model may not precisely assess the severity of heavy-metal pollution, it nevertheless indicates the need to consider the effects of low temperature and fluctuating temperature on heavy-metal toxicity.

Acknowledgments

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Effects of Thiourea Treatment on Sexually Maturing and Gonadectomized Male Sockeye Salmon (*Oncorhynchus nerka*)

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McBride, J. R., and A. P. van Overbeeke. 1975. Effects of thiourea treatment on sexually maturing and gonadectomized male sockeye salmon (*Oncorhynchus nerka*). J. Fish. Res. Board Can. 32: 11–19.

Adult male sockeye salmon in the final stage of sexual maturation were treated with thiourea for periods of 7–14 wk. The treatment produced strong histological thyroid stimulation but no visible effect on spermatogenesis or development of secondary sexual characteristics. The drug did not affect the interrenal hypertrophy that commonly occurs in these salmon, but slightly inhibited the increase in thickness of the skin. Thiourea induced changes in the pars distalis of the pituitary gland, involving several cell-types, including retardation of gonadotrop development.

In gonadectomized fish, thiourea affected neither the skin, nor the interrenal tissue. It caused a marked increase in the height of the thyroid epithelium, correlated with hypertrophy, degranulation, and some vacuolization of PAS-positive cells in the dorso-caudal area of the proximal pars distalis of the pituitary gland. Therefore, these last cells are considered thyrotrops.

McBride, J. R., and A. P. van Overbeeke. 1975. Effects of thiourea treatment on sexually maturing and gonadectomized male sockeye salmon (*Oncorhynchus nerka*). J. Fish. Res. Board Can. 32: 11–19.

Nous avons traité à la thiourée, sur une période de 7 à 14 semaines, des saumons nerka mâles adultes au dernier stade de maturité sexuelle. Le traitement produit une forte stimulation histologique de la thyroïde, mais n'a pas d'effet visible sur la spermatogénèse ni sur le développement des caractères sexuels secondaires. La drogue n'affecte pas l'hypertrophie interrénale qu'on observe communément chez ces saumons, mais paralyse légèrement l'épaissement de la peau. La thiourée provoque des changements dans la pars dorsalis de la glande pituitaire, impliquant plusieurs types de cellules, y compris un retardement du développement des gonadotropes.

Chez des poissons dont les gonades ont été enlevées, la thiourée n'affecte ni la peau ni le tissue interrénal. Elle cause une augmentation prononcée, liée à l'hypertrophie, de la hauteur de l'épithélium thyroïdien, une dégranulation et la formation de quelques vacuoles dans les cellules PAS-positif, dans la région dorso-caudale de la pars distalis proximale de la glande pituitaire. Ces cellules sont donc considérées comme thyrotropes.

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The mucoid cells (PAS-positive cells or so-called "basophils") in the pars distalis of the pituitary gland of teleost fishes comprise both gonadotrops and thyrotrops. In most species differentiation between these cell-types is hampered because their tinctorial and histochemical properties are similar. Also, the location of these cell-types especially that of the thyrotrops varies. The subject has recently been reviewed by van Oordt (1968) and Ball and Baker (1969).

The situation in salmonids illustrates the problems. In several species, moreover, the abundance, distribution pattern, and activity of the mucoid cells concerned seem to change considerably during the life history. A commonly used technique to identify thyrotrops is to suppress secretion of thyroid hormone. This interferes with the negative feedback control of pituitary thyrotropin secretion which in turns leads to visible depletion of the thyrotropic cells. Thus, in juvenile fish these cells, on the basis of their reaction to either radiothyroidectomy or treatment of the fish with the antithyroid drug thiourea, have been identified as thyrotrops; for instance in rainbow trout, *Salmo gairdneri* (Olivereau et al. 1964; Norris 1966), chinook salmon, *Oncorhynchus tshawytscha* (Olivereau and LaRoche 1965; Norris 1966; Olivereau 1972), and coho salmon, *Oncorhynchus kisutch*

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TABLE 1. Effect of thiourea on thyroid follicles, nuclear diameter on interrenal cells, and thickness of the epidermis in normal, sexually maturing, and gonadectomized male sockeye salmon (*Oncorhynchus nerka*).[a]

Experiment	No. of fish	Treatment	Duration (*wk*)	Thyroid epithelium height (μ)	Interrenal cells nuclear diameter (μ)	Epidermal thickness (μ)
Experiment 1 (1970):						
Group 1, immature fish	4	controls	0	5.94±0.79	6.07±0.24	82.00± 1.58
Group 2, mature fish	8	0.03% thiourea	14	13.68±2.11	7.15±0.19	209.19±30.65
Group 3, mature fish	4	controls	14	3.43±0.22	7.15±0.08	233.75±20.97
Experiment 2 (1970–71):						
Group 1, gonadectomized fish	5	0.03% thiourea	14	9.83±2.26	6.11±0.02	46.50± 9.12
Group 2, gonadectomized fish	4	controls	14	3.93±0.64	6.00±0.13	45.00± 7.90
Experiment 3 (1971):						
Group 1, immature fish	4	controls	0	6.25±0.64	6.27±0.03	79.75± 1.26
Group 2, maturing fish	5	0.06% thiourea	7	11.49±2.13	6.29±0.08	125.50±13.85
Group 3, maturing fish	5	controls	7	5.34±0.65	6.47±0.22	145.90±11.60
Group 4, mature fish	7	0.06% thiourea	14	13.00±2.12	7.05±0.14	210.71±29.88
Group 5, mature fish	2	controls	14	4.34±0.12	7.11±0.10	235.00±24.75

[a]Mean values in microns ± standard deviation.

(Chestnut 1970). In adult salmon, on the other hand, the mucoid cells are usually related to the gonadotropic function. Robertson and Wexler (1962) suggested this relationship in their pioneer study of the pituitary gland of sexually maturing Pacific salmon (mostly *Oncorhynchus tshawytscha*). Similarly, in mature sockeye salmon, *Oncorhynchus nerka*, the PAS-positive cells were considered gonadotrops (van Overbeeke and McBride 1967), a designation supported by their rapid degranulation following gonadectomy (McBride and van Overbeeke 1969). Further, McKeown and van Overbeeke (1971) showed that these cells are capable of binding fluorescent anti-ovine luteinizing hormone but not anti-bovine thyrotropin. It may be concluded that in adult Pacific salmon no thyrotrops have been identified. Yet, it seems unlikely that such cells are totally absent. First, Chestnut (1970), who considered the PAS-positive cells that abound in the pituitary glands of reproducing coho salmon to be mostly typical gonadotrops, demonstrated clearly that these glands possess thyrotropic potency. Also, McBride and van Overbeeke (1969) showed that a few PAS-positive cells in the sockeye salmon did not undergo degranulation following gonadectomy; these therefore, might have been thyrotrops. Finally, Cook and van Overbeeke (1972), in an electron microscopic study of the sockeye pituitary gland, suggested that thyrotropic cells are present, but contain only very small and relatively few granules, which would make them appear as agranular, weakly stained cells when viewed with the light microscope.

The present communication concerns the effects of thiourea treatment on the pituitary gland of adult male sockeye salmon. Intact, sexually maturing fish, as well as gonadectomized fish, were used in an attempt to identify the thyrotropic cells. In addition, the effect of thiourea on maturation of the testes and on changes normally associated with sexual maturation in sockeye salmon were investigated.

Materials and Methods

In July 1970 and 1971 immature sockeye salmon were captured during their spawning migration to Great Central Lake, Vancouver Island, B.C. Methods of capture and transportation to the Vancouver Laboratory have been described earlier (McBride et al. 1963). Only males weighing between 1650 and 2400 g were used. Fish were kept under natural photoperiod conditions in 908 liters (200 gal) fiberglass tanks, four fish per tank. Water temperature was controlled at 10 ± 1 C. Thiourea was administered by dissolving the drug in the water of the tanks. Fresh water of the control tank as well as the thiourea solutions were renewed every second and fifth day of the week. To minimize the build-up of waste products in the stagnant water, fish were not fed during the experimental period.

Experiment 1 (effect on normal maturing fish; July–October 1970) — There were three groups: one group of four immature controls was killed at the beginning of the experiment; a second group, eight fish, was kept in 0.03% thiourea for 14 wk and then killed; and a third group of four fish served as terminal controls. These last two groups were mature by the end of the experiment.

Experiment 2 (effect on gonadectomized fish; November 1970–February 1971) — In July 1970 a number of males were gonadectomized while still immature ("sea-green fish"), within 2 wk after capturing. They were then induced to resume feeding (see McBride 1967). Feeding continued until the beginning of the thiourea treatment. Of these operated salmon, nine apparently healthy fish, lacking any sign of secondary sexual characteristics, were selected in November. One group of five was treated during 14 wk in 0.03% thiourea and killed in February 1971, along with a group of four control fish.

Experiment 3 (effect on normal maturing fish; August–November 1971) — This experiment was similar to experiment 1. Four fish were killed at the beginning of the experiment; five fish were treated in 0.06% thiourea for a period of 7 wk and then killed along with five controls; in another group, seven fish, the thiourea treatment lasted 14 wk; two fish served as terminal controls. The organization of the experiments is summarized in Table 1.

Histological techniques — Fish were immobilized by severing the spinal cord. Samples were taken from the skin, at a point midway between the dorsal fin and the lateral line; head kidney, containing the interrenal tissue; subpharyngeal region, containing the thyroid follicles; and testes. Pituitary glands were dissected and fixed in toto. All tissues were fixed in Bouin-Hollande-sublimate; dehydrated, and processed for embedding in Paraplast, mp 56 C. Pieces of skin and of the subpharyngeal region were decalcified in 5% HNO_3 in 70% ethanol for 4 h. Tissues were sectioned at a thickness of 5 μ. Staining procedures used were: Masson's trichrome method, including Ponceau de xylidine (Culling 1957); periodic acid–Schiff (PAS)–Orange G (Culling 1957); Alcian blue–PAS (McManus and Mowry 1960); lead–hematoxylin (McConaill 1947); and Mayer's hematoxylin–eosin (Culling 1957).

Histometry — For each fish the histological thyroid activity was determined by measuring the epithelium height at four separate locations in each of six randomly selected follicles. Similarly, an index of interrenal activity was obtained by measuring the diameter of 30 randomly selected cell nuclei. Finally, the thick-

ness of the epidermis was measured at four different points within each sample of skin tissue.

Results

Experiments 1 and 3 — As the results of these two experiments are essentially the same, they will be presented together.

Testes — No differences were found between controls and thiourea-treated fish. The period of experimentation coincided with the last phase of spermatogenesis. The testes of the control fish killed in July or early August contained small numbers of spermatogonia, large amounts of primary and secondary spermatocytes, and, at least in some fish, small groups of spermatids. In the terminal controls the gonads consisted almost exclusively of spermatozoa and small clumps of spermatids.

Neither was there a visible effect of thiourea treatment on the development of external characteristics of sexual maturity. All fish developed the typical nuptial skin coloration, hooked snouts, and large premaxillary teeth.

Thyroid gland — The vast majority of the thyroid follicles was smaller than 150 μ in diameter. A small number, estimated at approximately 5–10%, were larger, ranging between 150 and 500 μ. In all control fish the follicles had the characteristic low epithelium of sockeye salmon approaching maturity. Many cell nuclei were shrunken, and the intrafollicular colloid was strongly PAS-positive, containing only a few small marginal vacuoles. In the terminal controls the epithelium was lower than in the fish killed at the beginning of the experiment (Table 1). Thiourea administration at .03 and .06% increased the height of the epithelium (Table 1). Also, in the thiourea-treated fish the colloid was only weakly PAS-positive and contained many more vacuoles than in the controls. The two concentrations used, 0.03 and 0.06%, exerted an equally strong effect. Moreover, in experiment 3, there was no significant difference in effect between the 7-wk and the 14-wk treatment.

Interrenal tissue — Thiourea treatment did not noticeably affect the interrenal hypertrophy (Table 1). During the experiments the interrenal tissue of the control fish became hypertrophic. The increase in nuclear diameter in the control fish during the period of 14 wk was significant. This phenomenon was similar to the interrenal hypertrophy observed earlier in sexually maturing sockeye salmon (McBride and van Overbeeke 1969b).

Skin — In the controls the thickness of the skin increased markedly. This integumentary hypertrophy involved the epidermal layer as well as both the reticular zone and the stratum compactum of the dermis and is commonly observed in sockeye salmon at this stage of their life history (McBride and van Overbeeke 1971). As the epidermal changes were more conspicuous than those in the dermis and since the epidermis is also more amenable to measurements, the latter was used to quantify the alterations. During the experimental period the thickness of the epidermis increased approximately threefold (Table 1). Not only did the number of cell layers of this stratified epithelium increase, but there was also a marked enlargement of individual cells, most conspicuously of the columnar cells in the germinal layer. Thiourea treatment somewhat inhibited the skin hypertrophy. In all three experimental groups the epidermis was thinner in the thiourea-treated fish than in the corresponding control groups.

Pituitary gland — Collectively, the pituitary glands of the various groups of control fish illustrated the characteristic alterations that take place in this gland during gonad maturation[2]. The most notable change concerned the differentiation of the gonadotrophic cells (granulated PAS-positive cells or "basophils"; cell-type 2 and 6[3]). In fish killed at the beginning of the experiment, such cells were generally sparse and found only in the proximal pars distalis near the ventral projection of the rostral pars distilas, or even absent in some fish. In terminal controls they were abundant and distributed throughout both parts of the pars distalis (Fig. 1). Shrunken PAS-positive cells with pyknotic nuclei were commonly observed as well. Differentiation of the gonadotrops was accompanied by a drastic reduction in the number of undifferentiated cells. Characteristic, too, was the near-disappearance of the large agranular "chromophobes" (cell-type 7). In early control fish, these cells, which often showed a faint PAS-positive cytoplasm, were numerous and in some fish showed considerable mitotic activity. Occasionally their cytoplasm showed beginning vacuolar disintegration. In terminal control fish, nearly all cells of this category that were left were degeneratively affected. Growth hormone cells (acid-

[2]Only a summary of these changes is reported, as a detailed description has been published (van Overbeeke and McBride 1967; McBride and van Overbeeke 1969a).

[3]Cell-types designated by numbers were described earlier (van Overbeeke and McBride 1967).

ophils, cell-type 5) seemed to become slightly more abundant as well as larger during the experiments. Control fish kept for 7 wk (experiment 3) showed features intermediate between those of the two groups referred to above. In this last group there were no pyknotic PAS-positive cells.

Thiourea administration inhibited most of the changes just mentioned. In four of the five fish treated with thiourea for a period of 7 wk, there were fewer gonadotrops, more undifferentiated cells and more "chromophobes" than in the corresponding control fish. In these four fish, the gonadotrops were only sparsely distributed throughout the rostral pars distalis, fairly abundant in the adjacent zone of the proximal pars distalis, but virtually absent in the deeper parts of this last lobe. "Chromophobes" were not only more numerous than in the controls, but also largely intact, several showing mitosis. In one thiourea-treated fish the pituitary cytology did not visibly differ from that in the controls. This same fish had a thyroid epithelium height of 8.6 μ, lower than the others in the group where this value varied from 11 to 14 μ. The effects of thiourea were more pronounced after 14 wk (Fig. 2). Although gonadotrops were now abundant, they were still sparsely distributed in the central and posterior parts of the proximal pars distalis. Also, in the control fish these cells generally contained numerous large granules, whereas in thiourea-treated fish both the size and the number of these granules were reduced. This was noticed best in Alcian blue–PAS-stained sections. With this technique only the large globular inclusions stained purple while the smaller granules are dyed bright blue. Pyknotic degeneration of gonadotrops was observed only in 4 out of 15 thiourea-treated fish. Undifferentiated cells were less abundant than those in fish treated for 7 wk, but clearly more abundant than in the controls. "Chromophobes" were still numerous after 14 wk of thiourea treatment, but mitotic figures were no longer present and cytoplasmic degeneration was widespread. No clear effect of the drug on the somatotrops could be detected.

Experiment 2 — When the experiment began in November, all fish showed external features indistinguishable from those of so-called "sea-green," sexually immature sockeye salmon. Neither controls nor thiourea-treated fish changed visibly during the experiment. No differences in behavior between the two groups were noticed. None of the fish appeared to have remnants of testicular tissue.

Thyroid gland — Virtually all thyroid follicles were smaller than 150 μ in diameter. In the control fish, the epithelium was squamous and neither the cells, nor the follicle contents differed from those in the terminal control fish of the experiments 1 and 3 (Table 1). Thiourea administration brought about a marked increase in epithelium height (Table 1).

Interrenal tissue — Thiourea did not visibly affect the condition of this tissue (Table 1). In the controls the interrenal tissue resembled that of sexually immature fish. There were no signs of hypertrophy and the average nuclear diameter had the same value as that of the interrenal cell nuclei of the controls killed at the beginning of the two other experiments.

Skin — In all fish, the thickness of the integument was reduced compared to that at the time of gonadectomy (Table 1). The values for the height of the epidermis are illustrative. The stratum germinativum consisted of cuboidal, rather than columnar cells. No effect of thiourea treatment could be detected.

Pituitary gland — In the control fish the proximal pars distalis consisted almost exclusively of somatotrops and small groups of undifferentiated cells, located near the pars nervosa. Typical gonadotrops could not be detected. There were, however, a few small PAS-positive cells in the dorso-caudal area. In the smallest of these, the cytoplasm seemed to be PAS-positive but in others minute PAS-positive granules could be discerned. In Masson-stained sections these cells were light green (Fig. 3). Their nuclei were small and mostly kidney-shaped.

In the thiourea-treated salmon, the proximal pars distalis was also dominated by growth hormone cells. In one fish of this group the cytological picture did not differ from that of the controls. In the four others there were fewer undifferentiated cells which, moreover, were relatively large and showed mitotic figures. More conspicuously, each of these four fish had numerous cells resembling the "chromophobes" commonly found in sexually maturing salmon (Fig. 4). Cells of this type varied from relatively small ones with moderate amounts of minute PAS-positive granules, to very large ones containing weakly stained PAS-positive cytoplasm but without granules and often showing vacuolar degeneration. Their nuclei were mostly large, spherical, rich in chromatin, and often with large nucleoli. In these cells mitotic figures were frequently observed.

Discussion

The results of this study confirm an earlier established relationship between sexual maturation and interrenal hypertrophy in sockeye salmon (McBride and van Overbeeke 1969b). Hyperfunction of the adrenocortical homologue during this period is caused by gonadal hormones (Fagerlund and Donaldson 1969; Donaldson and Fagerlund 1969; van Overbeeke and McBride 1971). The present study demonstrates that the hyperadrenocorticism is unaffected by inhibition of thyroid function.

An increase in thickness of the skin in maturing sockeye has also been noticed previously (McBride and van Overbeeke 1971). Thiourea treatment seemed to reduce the integumentary reaction. This observation and the absence of a thiourea effect on the skin in gonadectomized salmon suggest that thyroid hormone enhances the skin-effect of gonadal hormones but does not itself directly affect the skin. In other species of teleosts such direct effects of the thyroid have been observed. Baker (1964) reported that thiourea not only reduced the thickness of the skin but also caused degeneration of its mucous glands in young *Herichthys cyanoguttatus*. In salmonids a similar effect was noticed by Sembrat (1954), while LaRoche and LeBlond (1952) made a complementary observation, namely a thickening of both the epidermis and the derma in juvenile *Salmo salar* and *Salvelinus fontinalis* following thyroxine administration.

The effect of thiourea on the pituitary gland was clearest in the gonadectomized fish. The induction in these fish of strongly hypertrophied thyroid epithelium and the appearance of considerable numbers of partly or completely degranulated, weakly PAS-positive cells indicate that the latter are thyrotrops. Their location was the same as that of the few, small, PAS-positive cells present in the control fish. The thiourea-induced decrease in abundance of undifferentiated cells and the occurrence in them of mitoses indicate recruitment of new thyrotrops in addition to hyperplasia of existing cells. The only specimen in the thiourea-treated group where the PAS-positive cells had not undergone changes showed also a minimal effect on the thyroid epithelium (mean epithelium height: 6.9 μ; the others in the group ranging from 8.3 to 12.4 μ).

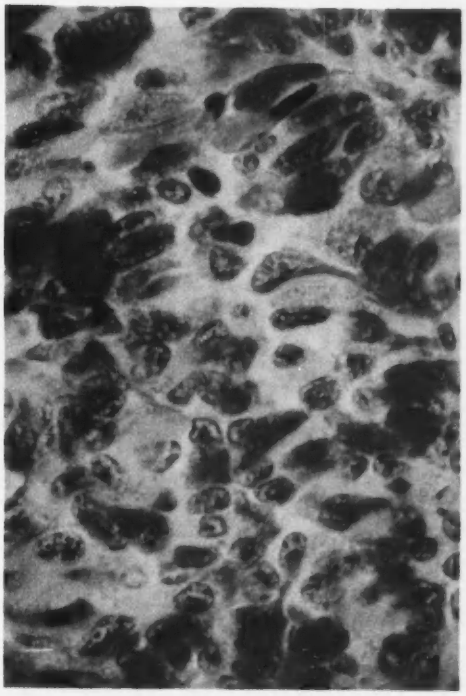
The effect of thiourea on the pituitary gland of sexually maturing fish is more complex. In these fish neither spermatogenesis nor development of secondary sexual characteristics was affected. Yet the drug inhibited the histological changes in the pars distalis that normally accompany maturation, including the differentiation of gonadotrophic cells. Effects of thiourea on gonadotrops and gonadal activity have been reported for several teleosts. According to Pandey (1970) and Pandey and Leatherland (1970, 1971) in *Poecilia reticulata* both oogenesis and spermatogenesis are blocked by thiourea treatment and this effect is accompanied by inhibition of gonadotrop differentiation, particularly in juvenile fish. Sage and Bromage (1970), using the same species, however, reported a thiourea-induced increase in activity of gonadotrops in cultured pituitary glands, while thyroxine caused inactivation of these cells. Mackay (1973) noticed that in *Hypseleotris galii* thiourea caused inhibition of vitellogenesis, but he attributed this to a general toxicity of the drug. In *Cymatogaster aggregata* thiourea did not affect gonadotrophic activity (Wiebe 1968) and absence of a thiourea effect on the gonadotropic cells of *Anoptichthys jordani* was also reported by Mattheij (1969).

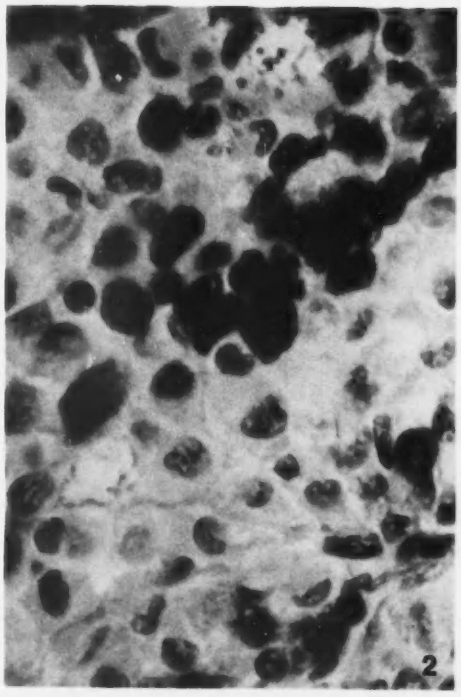
From these investigations no definite conclusions can be drawn. Yet, it seems evident that in teleosts thiourea not only causes the well-known degranulation of thyrotrops, correlated with thyroid hypertrophy but, at least in some species, also affects the gonadotrops. Our own results,

FIGURES 1–4.

Illustration of the PAS-positive cells, particularly where they are only lightly stained, is often difficult. In Fig. 1–4 the sections were processed with the more intense staining Masson's trichrome method. The PAS-positive cells or basophils are green.

FIG. 1. Central area in the proximal pars distalis of the pituitary gland of a sexually mature male sockeye salmon (*Oncorhynchus nerka*). Note abundance of well-granulated gonadotrops (green). Fuchsinophil cells (red) are somatotrops. Masson trichrome ×250; FIG. 2. Central area in the proximal pars distalis of the pituitary gland of a sexually mature male sockeye salmon, treated with 0.06% thiourea for 14 wk. There are only a few gonadotrops. Note numerous chromophobes, some of which show cytoplasmic degeneration. Compare with Fig. 1. Masson trichrome. ×250; FIG. 3. Dorso-caudal area of the proximal pars distalis of the pituitary gland of a male sockeye salmon, 7 mo after gonadectomy. Somatotrops (red) predominate in this area. A few thyrotrops (arrows) can be seen. Masson trichrome. ×160; FIG. 4. Dorso-caudal area of the proximal pars distalis of the pituitary gland of a male sockeye salmon, 7 mo after gonadectomy. Fish treated with 0.03% thiourea for 14 wk. Note abundance of hypertrophied, degranulated, and occasionally vacuolated thyrotrops. Compare with Fig. 3. Masson trichrome. ×160.

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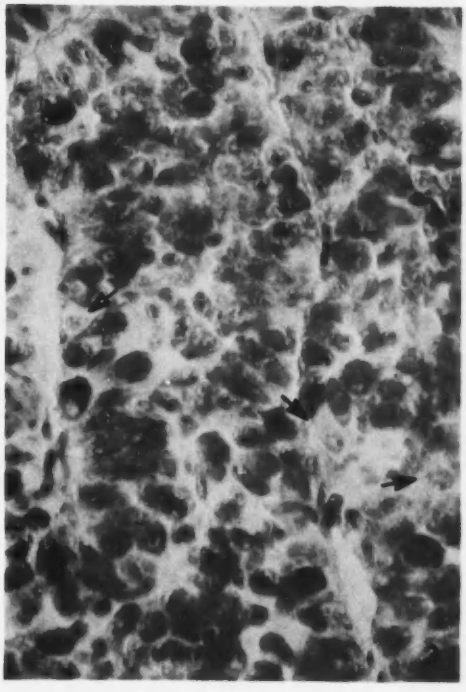

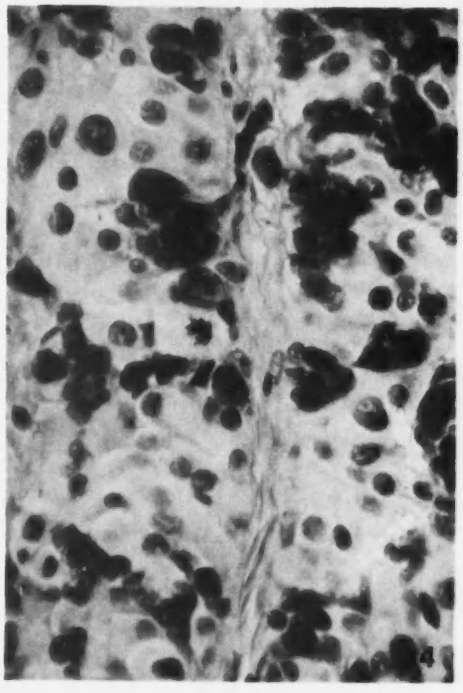
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showing a general influence on the pars distalis involving several cell-types rather than degranulation and hypertrophy of one specific cell-type, suggest that thiourea acted indirectly and that the effect on the pituitary gland may have been due to inhibition of thyroid hormone production. The absence of a specific response of one cell-type hampered identification of any thyrotrops. Such identification was further complicated by the presence of the so-called "chromophobe cells." Presumably, thiourea would have affected the thyrotrops in a manner similar to that in the gonadectomized fish, thus producing hypertrophied, degranulated, and vacuolized cells undergoing mitosis. Such cells, however, are indistinguishable from the "chromophobes" that occurred in both the controls and thiourea-treated intact fish. The question arises whether these "chromophobes" might in fact be thyrotrops in a state of hypertrophy. We consider this as most unlikely, since the thyroid gland in the control fish is indicative of a reduced, rather than a hyperactive thyrotropin production. In our opinion, the condition of the thyrotrops in the sexually maturing sockeye used in this study is probably not different from that in the gonadectomized fish. As their number is probably very small they would be indistinguishable from developing gonadotrops. The functional significance of the "chromophobes" remains to be elucidated. They may well represent gonadotrops in a state of degranulation, as was earlier suggested on the basis of their ultrastructural characteristics by Cook and van Overbeeke (1972).

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Systematic Status of a Midwater Population of Freshwater Sculpin (*Cottus*) from Lake Washington, Seattle, Washington[1]

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LARSON, K. W., AND G. W. BROWN JR. 1975. Systematic status of a midwater population of freshwater sculpin (*Cottus*) from Lake Washington, Seattle, Washington. J. Fish. Res. Board Can. 32: 21–28.

A population of freshwater sculpin from Lake Washington differs from other species of the typically benthic genus *Cottus* in that individuals migrate nightly to the surface and midwaters. Individuals are phenotypically and biochemically similar to *Cottus aleuticus*, but have a longer, more terete body, a larger cephalic pore and canal system, shorter pelvic fins, and a higher frequency of individuals with seven branchiostegal rays per side.

A close relationship between the Lake Washington population and *C. aleuticus* seems indicated because of their phenotypic and biochemical similarities and because of the existence of individuals in other Northwest lakes that appear intermediate in character between *C. aleuticus* and the Lake Washington population. The decision as to the specific status of the Lake Washington population is deferred until more is known of its degree of reproductive isolation from *C. aleuticus* and of the existence of these possibly intermediate populations.

LARSON, K. W., AND G. W. BROWN JR. 1975. Systematic status of a midwater population of freshwater sculpin (*Cottus*) from Lake Washington, Seattle, Washington. J. Fish. Res. Board Can. 32: 21–28.

Une population de chabots d'eau douce du lac Washington diffère des autres espèces du genre *Cottus* typiquement benthique, en ceci que ses membres émigrent chaque nuit vers la surface ou entre deux eaux. Des points de vue phénotypique et biochimique, les individus ressemblent à *Cottus aleuticus*, mais ils ont un corps plus long et plus térétiforme, un pore et des canaux céphaliques plus grands, des nageoires pelviennes plus petits et une plus grande fréquence d'individus à sept rayons branchiostèges de chaque côté.

On serait justifié de conclure à une étroite relation entre la population du lac Washington et *C. aleuticus*, à cause de leurs similarités phénotypique et biochimique et aussi parce qu'il existe, dans d'autres lacs du nord-ouest, des individus dont les caractères semblent intermédiaires entre *C. aleuticus* et la population du lac Washington. Les auteurs remettent à plus tard la décision sur le statut spécifique de la population du lac Washington, en attendant qu'on sache davantage à quel point il y a barrière reproductrice entre elle et *C. aleuticus* et qu'on soit mieux renseigné sur l'existence de ces populations possiblement intermédiaires.

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DURING a series of midwater trawls made in Lake Washington, in 1963 and 1964, a number of freshwater sculpins of the genus *Cottus* were collected. These sculpins appeared to be distinct from other known species of the typically benthic genus *Cottus* in that individuals were regularly collected at night near the surface and in the midwaters of the lake.

This population from Lake Washington has been little investigated. Dryfoos (1965) first indicated its presence in Lake Washington. Ikusemiju (1967) found that individuals of the population migrate vertically into the mid- and surface waters of the lake largely at night. He proposed either predation on mysid shrimp or a competitive feeding situation on the bottom of the lake as possible explanations for the vertical migration. However, neither explanation has proved satisfactory.

Neither Ikusemiju nor Dryfoos described the systematics of the population, nor did they discuss its relationship with other members of the genus.

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In the present paper, the morphology and biochemistry of the population is described and a discussion is presented regarding its relationship to other species of the genus and its possible specific status.

Materials and Methods

Sculpins were obtained from the collections made by Dryfoos (1965) and those made by K. W. L. during 1971 and 1972. These sculpins have been listed by Dryfoos (1965) and Larson (1972) and are deposited in the fish collection of the College of Fisheries, University of Washington. All collections were made in the lake using a 3-m Isaacs-Kidd midwater trawl with a 3.2-mm mesh cod end.

Morphological Methods

Morphological data were taken according to the methods of Hubbs and Lagler (1967) with the following exceptions:

Body depth: depth at the anal fin insertion;

Caudal peduncle length: the straight line length from the base of the last anal ray to the posterior edge of the hypural plate;

Length of dorsal and anal fins: the straight line length from the base of the first element to the base of the last element, including both spined and rayed portions of the dorsal fin;

Number of dorsal fin spines and rays and anal fin rays: follows the method of Robins and Miller (1957).

All measurements were taken to the nearest 0.1 mm with dial calipers. Counts of the trunk and caudal vertebrae were made on radiographs of Kodak M-54 industrial X-ray film with a defraction tube X-ray machine. The caudal vertebrae count began with the first vertebra having a definite hemal arch and included the urostyle.

Terminology of cephalic pores and canals followed that of Robins and Miller (1957). Osteological data were taken following clearing and staining according to the method of Davis and Gore (1947).

Biochemical Methods

The horizontal starch gel electrophoresis system of Beckman and Johnson (1964) was used to analyze the isozymes of lactate dehydrogenase (LDH) (EC 1.1.1.27) and malate dehydrogenase (MDH) (EC 1.1.1.37). White muscle, liver, and eye tissues from individuals of the population in Lake Washington were compared to those of four benthic species of *Cottus*: *C. aleuticus*, *C. bairdi*, *C. cognatus*, and *C. asper*. *Cottus aleuticus* and *C. bairdi* were collected from streams of the Lake Washington drainage. *Cottus asper* was collected from streams in the Lake Washington drainage, as well as from the benthic and littoral areas of the lake. *Cottus cognatus* was collected from First Creek, Lake Chelan, Washington. The number of individuals compared is shown below.

	White muscle	Liver	Eye
Lake Washington population	50	5	5
C. aleuticus	57	5	5
C. asper	15	5	5
C. bairdi	10	5	5
C. cognatus	4	0	0

Sculpins for electrophoretic analyses were brought back to the laboratory alive, and frozen and stored at –20 C. Tissue samples were homogenized (1 part tissue to 2 parts distilled water), freeze-thawed twice in baths of dry ice in ethanol and in warm water, then centrifuged at room temperature for 15 min at 1650 × *g*. The supernatant was stored at 0 C until studied.

Samples were compared on gels of 15% hydrolyzed starch (Connaught Medical Research Laboratories, Toronto, Canada) with either the Tris-citrate (pH 7.0) buffer system of Shaw and Prasad (1970) or with the LiOH discontinuous buffer system of Ridgway et al. (1970). The Tris-citrate system was used primarily for MDH analyses and was run at 7.65 V/cm for 5 h. The LiOH system was used primarily for LDH and was run at 12.76–15.30 V/cm until the borate boundary had migrated 6 cm from the origin. Both systems gave comparable electrophoretic results. LDH and MDH were localized on the gel according to the staining method of Shaw and Prasad (1970) except one half the quantity of reagents was used with no noticeable effect on the results.

Morphology

Individuals of the population of sculpins in Lake Washington are small in size; a maximum standard length of 57.8 mm and an average standard length of 31.2 mm was obtained for the 376 individuals examined. The general body shape is illustrated in Fig. 1. The average body proportions and the fin rays and vertebral counts for 100 individuals ranging in size from 18.0 to 57.8 mm SL are listed in Tables 1 and 2 (shown in comparison with values from 100 *C. aleuticus*, 21.0 to 51.3 mm SL, collected from streams in the Lake Washington drainage).

All spinous and soft fin rays of individuals of the Lake Washington population are unbranched, except the last ray of the dorsal and anal fin which may be variously branched to completely split in two. The caudal fin has six principal rays per hypural with five rays branched on the dorsal hypural and four branched on the ventral hypural. The branchiostegal rays were counted on both sides and the frequency of each count is given in parentheses: 6, 6 (17); 6, 7 (17); 7, 7 (65); 8, 8 (1).

The cephalic pore and canal system is well developed and the pores and canals are large (Fig.

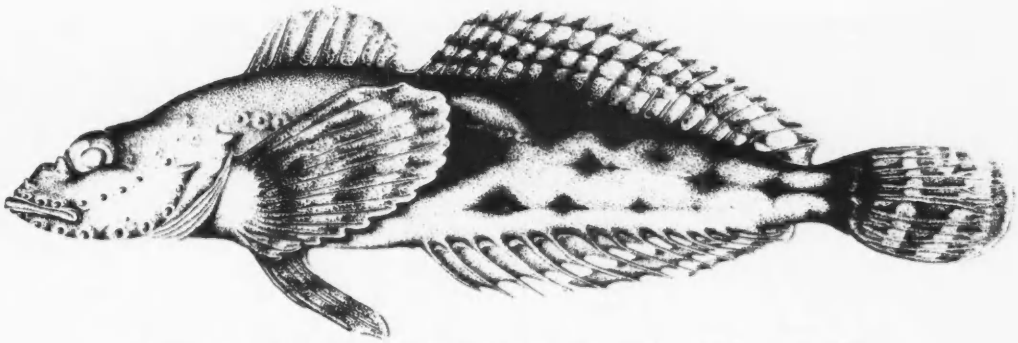

FIG. 1. An individual of the Lake Washington population, 40.3 mm SL male.

TABLE 1. Comparison of the measurements of the Lake Washington population and *Cottus aleuticus*, expressed as proportions of the standard or head length, showing the mean and range for 100 individuals, the standard deviations, the *F* values, and the degrees of freedom (df) as computed by the discriminate function.

Measurement (expressed as proportions of SL)	*Cottus aleuticus*	Lake Washington population	*F* value (df)	*P*
Length of pelvic fin	5.7±0.54 (4.71–7.34)	6.8±0.76 (3.84–9.81)	69.44 (1–197)	>0.001
Body depth	5.7±0.33 (5.12–6.54)	6.8±0.59 (5.67–8.43)	31.64 (1–195)	>0.001
Height of longest dorsal ray	7.5±0.64 (5.80–9.33)	7.2±0.59 (5.64–9.15)	12.60 (1–194)	>0.001
Length of anal fin	3.2±0.18 (2.83–3.92)	3.1±0.21 (2.25–3.61)	10.33 (1–193)	>0.001
Caudal peduncle length	6.5±0.81 (4.96–9.05)	6.1±0.73 (4.67–8.25)	4.64 (1–191)	>0.05
Predorsal length	3.2±0.16 (2.70–3.53)	3.1±0.18 (2.65–4.21)	3.04 (1–190)	<0.10
Head length	3.4±0.14 (3.04–3.76)	3.3±0.23 (2.89–4.95)	1.28 (1–188)	<0.10
Length of dorsal fin	1.6±0.06 (1.48–1.83)	1.7±0.11 (1.44–2.42)	1.27 (1–189)	<0.10
Length of pectoral fin	4.0±0.32 (2.94–4.86)	4.0±0.47 (3.19–7.00)	1.00 (1–186)	<0.10
Height of longest dorsal spine	12.7±1.41 (9.30–16.55)	11.6±1.20 (9.47–14.77)	0.74 (1–187)	<0.10
Height of longest anal ray	8.9±0.95 (6.78–11.30)	9.0±0.89 (6.71–13.20)	0.03 (1–185)	<0.10
Depth of head	6.2±0.38 (5.35–7.31)	7.3±0.72 (5.79–9.21)	0.01 (1–183)	<0.10
Measurement (expressed as proportions of head length)				
Caudal peduncle depth	4.3±0.37 (3.40–5.20)	6.9±0.91 (3.67–7.91)	268.50 (1–198)	>0.001
Interorbital width	7.7±1.00 (5.62–10.40)	12.7±2.87 (6.88–20.00)	44.50 (1–196)	>0.001
Snout length	3.5±0.28 (2.79–4.25)	3.6±0.47 (2.30–5.19)	4.10 (1–192)	>0.05
Postorbital head length	2.1±0.16 (1.00–2.45)	2.0±0.16 (1.32–2.70)	0.02 (1–184)	<0.10
Length of orbit	4.4±0.48 (3.28–5.94)	3.9±0.42 (2.46–4.67)	Not included in test	

TABLE 2. Meristic counts, percent frequencies, and chi square analysis of the Lake Washington population and *C. aleuticus*.

	Dorsal fin spines					Dorsal fin rays				
	7	8	9	10		16	17	18	19	20
Lake Washington population	8 (8.0)	44 (44.0)	46 (45.5)	3 (3.0)		0 (0.0)	0 (0.0)	11 (11.0)	42 (41.5)	48 (47.5)
C. aleuticus	1 (1.0)	43 (42.0)	57 (56.0)	1 (1.0)		5 (5.0)	9 (9.0)	44 (43.5)	42 (41.5)	1 (1.0)
	$\chi^2 = 7.62, (3), P = <0.10$					$\chi^2 = 78.9, (4), P = > 0.001$				
	Anal fin rays					Pectoral fin rays				
	12	13	14	15	16	13	14	15	16	17
Lake Washington population	0 (0.0)	2 (2.0)	33 (34.0)	53 (55.0)	9 (9.0)	0 (0.0)	4.5 (4.7)	50 (52.7)	36 (37.9)	4.5 (4.7)
C. aleuticus	8 (8.0)	31 (31.0)	59 (58.0)	3 (3.0)	0 (0.0)	1.5 (1.5)	16 (16)	68 (66.5)	16.5 (16.0)	0 (0.0)
	$\chi^2 = 94.4, (4), P = >0.001$					$\chi^2 = 22.2, (4), P = >0.001$				
	Trunk vertebrae					Caudal vertebrae				
	8	9	10	22	23	24	25	26	27	28
Lake Washington population	5 (3.0)	171 (97.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	7 (4.0)	98 (59.0)	58 (35.0)	3 (2.0)
C. aleuticus	5 (4.0)	128 (94.0)	3 (2.0)	1 (1.0)	4 (3.0)	2 (1.5)	37 (29.5)	76 (60.0)	6 (5.0)	0 (0.0)
	$\chi^2 = 4.1, (2), P = <0.10$			$\chi^2 = 71.3, (6), P = >0.001$						

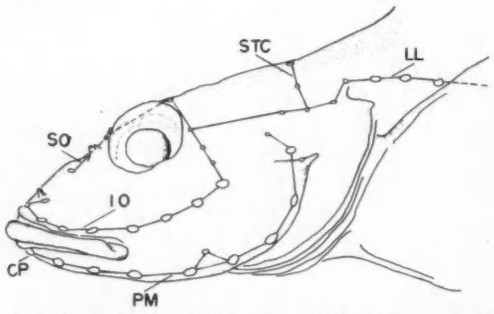

FIG. 2. Cephalic pores and canals of the Lake Washington population. CP, chin pore; LL, lateral line canal; IO, infraorbital canal; PM, preoperculo-mandibular canal; SO, supraorbital canal; STC, supra-temporal canal.

2). The preoperculo-mandibular canal is branched at the third pore and has pores numbering 9-1-9 (9th pore absent), 10-1-10, 10-10 (9th pore absent, double chin pores), or 11-11 with the frequency in 216 individuals examined being 55, 37, 5, and 3%, respectively. The first eight to nine preoperculo-mandibular pores, including the medial chin pore, are consistently 2–3 times the diameter of the nostrils. The infraorbital canal joins with the supraorbital and lateral line canals and has nine pores, with the first seven to eight of these larger than the nostrils. The supraorbital canal is branched anteriorly and has three to seven pores the size of the nostril openings. The supra-temporal canal joins the lateral line canal and has two to six pores the size of the nostril openings. The lateral line is variously complete; pores present on the caudal peduncle of a large (57.8 mm SL) specimen, but usually not present posterior to the middle of the soft rayed dorsal fin. Lateral line ossicles extend from the fourth or fifth dorsal spinous ray to the eighth soft ray of the dorsal fin and alternate with the pores, causing the lateral line to protrude from the body surface.

Prickles are present in the area axial to the pectoral fin. Individual prickle shape is similar to that described for *Cottus aleuticus* by McAllister and Lindsey (1959). A single obliquely directed spine is present at the angle of the preopercle.

The posterior and anterior nostrils are both tubular, and of similar height. Pharyngeal, vomerine, dentary, and premaxillary villiform teeth are present. Palatine teeth are absent. The anus is near the insertion of the anal fin, and the depressed pelvic fins fail to reach the anus.

Individuals of the Lake Washington population

are light to dark brown on the dorsal and lateral surfaces of the head and body. Darker brown saddles are visible under the dorsal fin, three under the soft rayed portion and two under the spinous portion. The ventral surface of the head and body is white to translucent. The dorsal, pectoral, and caudal fins are striped horizontally with dark brown to black bands on a white to translucent background. The anal and pelvic fins are white to translucent.

Biochemistry

The electrophoretic separation of the white muscle isozymes of lactate dehydrogenase (LDH) from the population in Lake Washington, *C. aleuticus*, *C. asper*, *C. bairdi*, and *C. cognatus* revealed a single anodal migrating band in all five forms (Fig. 3.). The single LDH band of the population in Lake Washington had an identical mobility with that of *C. aleuticus*, but differed from that of *C. bairdi*, *C. asper*, and *C. cognatus* (Fig. 3). The single LDH band of *C. asper* migrated the least anodally of the five forms. The LDH bands of *C. bairdi* and *C. cognatus* migrated the farthest of the five forms; the mobility of the bands in the two species seemingly were identical in the few individuals compared. There was also a single anodal migrating LDH band in the liver of individuals of the Lake Washington population, *C. aleuticus*, *C. asper*, and *C. bairdi*. The mobility of the LDH liver band was identical to that of the muscle LDH band of each of the four cottids (Fig. 3). The separation of the LDH isozymes of the eye in the four cottids revealed from one to three distinct anodal migrating bands. The least anodal migrating band had a mobility identical with that of the LDH white muscle and liver band of each of the four cottids and was always present. The two more anodally migrating bands varied widely in their presence, both individually and between species.

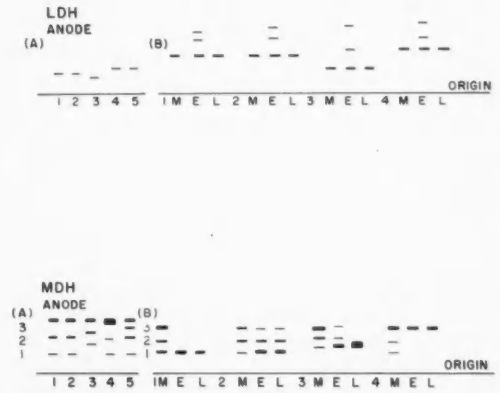

FIG. 3. Electropherogram of lactate dehydrogenase (LDH) and malate dehydrogenase (MDH) of muscle (A) and organ extracts (B) of the Lake Washington population: 1, *Cottus aleuticus*; 2, *C. asper*; 3, *C. bairdi*; 4, *C. cognatus*; 5, (M, muscle; L, liver; E, eye).

Electrophoretic separation of white muscle isozymes of malate dehydrogenase (MDH) in the five cottids revealed three distinct anodal migrating bands (MDH_1, MDH_2, MDH_3) in the Lake Washington population, *C. aleuticus*, *C. asper*, and *C. bairdi*, and four in *C. cognatus* (Fig. 3). The three MDH isozymes of the population in Lake Washington had identical mobilities with that of *C. aleuticus* and *C. bairdi*, but differed in mobility with the three bands of *C. asper* (Fig. 3). Liver and eye tissue had a single anodal migrating MDH band in both the Lake Washington population and *C. bairdi* (Fig. 3). In the population in Lake Washington, the liver and eye bands had identical mobilities with the MDH_1 white muscle band. In *C. bairdi*, the liver and eye MDH bands were identical in mobility with that of the MDH_3 white muscle band. In *C. aleuticus* three MDH bands were present in the liver and eye tissues, and their mobilities were identical with that of the three MDH white muscle bands.

Reproductive Ecology

The spawning period of the population in Lake Washington has been described by Ikusemiju (1967) as lasting from February to April with a peak in March. Ripe individuals were collected during these months in 1971 and 1972. The spawning location for the Lake Washington population is not known. However, ripe males and females were collected both in the midwaters and on the bottom of Lake Washington. In addition, no ripe individuals were collected in the limited sampling of the littoral areas of the lake or in the streams of the lake.

Ripe individuals of the population in Lake Washington ranged from 26.6 mm to 41.1 mm SL with an average of 36.5 mm for males (N=27), 35.7 mm for females (N=23), and 36.2 for both sexes (N=50). The male is sexually dimorphic with a long anal papilla and characteristic breeding colors. In the breeding male, the dorsal and lateral surfaces of the head and body are darker than those of the nonbreeding male with saddles still visible under the dorsal fin. The ventral surface of the head and body are lightly

speckled with black on a white to cream background. The spinous dorsal fin is also speckled with black and has a narrow orange to light yellow band on the upper edge of its spinous portion. The anal, pelvic, pectoral, and caudal fins are variously speckled with black on a light brown to white background. The breeding males of the Lake Washington population differ in color from the breeding males of *C. aleuticus* and *C. asper* collected from streams in the Lake Washington drainage. The latter are uniformly black with a bright orange band on the upper edge of the spinous dorsal fin.

The female of the Lake Washington population retains normal coloration during breeding and when gravid has small orange eggs. Ikusemiju (1967) determined the fecundity of 15 mature females and found the number of eggs per female to range from 114 to 298, with an average of 164.

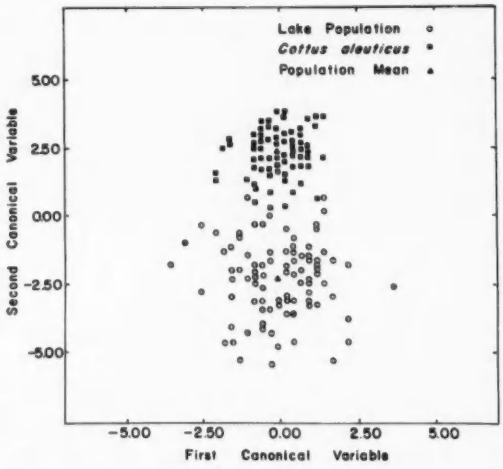

FIG. 4. Canonical analysis of the measurements from the Lake Washington population and *C. aleuticus*.

Relationship and Specific Status

The relationship of the population of sculpins in Lake Washington to other Pacific Northwest *Cottus* seems uncertain. Its occurrence in the midwaters of Lake Washington and apparent diurnal vertical migration render it ecologically distinct from other species of this typically benthic genus. In addition, when mature it is much smaller than other species of the genus. However, among the species of *Cottus* in the Pacific Northwest, the population appears phenotypically very similar to *C. aleuticus* and can be separated from the other species of the genus by the same characters that distinguish *C. aleuticus*. Both the population in Lake Washington and *C. aleuticus* can be distinguished by their tubular posterior and anterior nostrils, single sharp preopercular spine directed obliquely upward, pelvic fin count of I–4, prickles only in the area axial to the pectoral fin, and by their lack of palatine teeth.

One hundred individuals of the population in Lake Washington ranging in size from 18.0 to 57.8 mm SL were compared to similar size *C. aleuticus* (21.0 to 51.3 mm SL) collected in the streams in the Lake Washington drainage (Larson 1972). The measurements in Table 1 were compared statistically between the two populations using the BioMed computer program (BMDO7M) for the stepwise discriminate function (Dixon 1970). The program computed an F value that was used to indicate the probability of similarity or difference of the measurement. The comparison indicated that the population in Lake Washington has a significantly narrower head, body, caudal peduncle depth, and interorbital width and significantly shorter pelvic fins (Table 2). The other measurements either had probability values greater than 0.05 or had means and standard deviations that overlapped and were, therefore, not considered to differ between the two populations.

The program also compared all the measurements as a group between each population and indicated that the population in Lake Washington could be discriminated from *C. aleuticus* at a significance level less than 0.001 ($F_{(16,184)} = 52.01$). In addition, the program computed a graphic canonical analysis of the measurements by calculating canonical variables I and II for each fish of the two populations. The analysis showed the Lake Washington population and *C. aleuticus* as two distinct groups with minimum overlap (Fig. 4).

The counts in Table 2 were compared between the two populations by chi-square analysis (Simpson et al. 1960). Chi square was used to determine if any statistically significant differences existed between the distribution of the counts of the two populations. The comparison indicated that the population in Lake Washington has significantly greater numbers of individuals with higher dorsal, anal, and pectoral fin ray and caudal vertebrae counts, as well as a greater frequency of individuals with seven branchiostegal rays per side.

The cephalic pore and canal system of the population in Lake Washington is similar to that of *C. aleuticus*, both in the number of pores and

the location of the canals. In *C. aleuticus*, though, the canals are small and the pores are the same size or smaller than the nostril openings, whereas in the population in Lake Washington, the canals are large and the pores are 2–3 times the size of the nostrils. In addition, the cavities in the bones of the neurocranium that enclose the canals and the openings in these cavities for the pores are larger in the Lake Washington population than in *C. aleuticus*.

Biochemically, the population in Lake Washington was very similar to *C. aleuticus*. The mobilities and banding patterns of the LDH and MDH isozymes of the white muscle and organ tissues were, in most cases, identical with those of *C. aleuticus*, and could be separated from those of *C. asper*, *C. bairdi*, and *C. cognatus* (Fig. 3). However, the Lake Washington population differed from *C. aleuticus* by the presence of only one MDH band in the liver and eye tissues.

The phenotypic and biochemical similarities of the Lake Washington population to *C. aleuticus* seems to indicate a closer relationship than with any other Pacific Northwest cottid. This seems particularly true when evidence from other lakes in the Northwest is considered. Ricker (1960) has described a "dwarf" (49 mm TL) population of *C. aleuticus* from Cultus Lake, British Columbia. The population is apparently confined to the deeper areas of Cultus Lake where it is preyed upon by Dolly Varden char, *Salvelinus malma*. Two sculpins (29.1 and 26.2 mm SL) collected by tow net near the surface of Cultus Lake appeared to be intermediate between the population in Lake Washington and *C. aleuticus* from the Lake Washington drainage. Both individuals had preoperculo-mandibular pores the size of the diameter of the nostrils with the other cephalic pores the size of the nostril openings. Counts and measurements of the individuals were taken as described previously and are as follows: dorsal fin rays IX–20, VIII–19; anal fin rays 14,14; pectoral fin rays 15,15; branchiostegal rays 6,6 –; body depth 7.8, 7.0; caudal peduncle length 6.2, 6,1; interorbital width 9.9, 9.0 and pelvic fin length 6.9, 7.0.

A similar situation was found in Lake Sammamish, a lake located east of Lake Washington and connected to it by the Sammamish River. Of some 35 mature individuals collected in the midwaters of Lake Sammamish by tow net 27 were similar to *C. aleuticus*. The eight others ranging in size from 30.8 to 39.2 mm SL were, in varying degrees, intermediate between the population in Lake Washington and *C. aleuticus*. The data on the existence of intermediate populations in Cultus Lake and Lake Sammamish is not conclusive since an extensive comparison was not done. However, the data would seem to indicate the possibility of intermediate populations existing within these lakes, and also the possibility that the population in Lake Washington may have diverged from the typical *C. aleuticus* form and that a similar divergence may be occurring in other lakes in the Pacific Northwest.

The specific status of the Lake Washington population is uncertain. On the basis of its vertical migration, its large cephalic pore system and the presence of only a single MDH isozyme in the liver and eye tissues it would seem that the Lake Washington population is at least partly genetically and reproductively isolated from *C. aleuticus* and perhaps deserving of specific status. However, the actual breeding location of the Lake Washington population and its degree of reproductive isolation from *C. aleuticus* is uncertain. Also, even though the two populations can be separated statistically, the ranges of many of the characters overlap to such an extent that an incomplete divergence is indicated. An incomplete divergence would also seem to be indicated by the biochemical similarities. In addition, the existence of populations in other Northwest lakes which are possibly intermediate in character between the Lake Washington population and *C. aleuticus* may also indicate that divergence is not yet complete. On this basis, the decision as to the specific status of the Lake Washington population is deferred until more is known concerning both the degree of reproductive isolation between the Lake Washington population and *C. aleuticus* and the existence of similar, perhaps intermediate, populations in various stages of divergence in other Pacific Northwest lakes.

Acknowledgments

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Identification of *Anisakis* Larva (I) as *Anisakis simplex* (Rudolphi, 1809, det. Krabbe 1878) (Nematoda: Ascaridata)

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PIPPY, J. H. C., AND P. VAN BANNING. 1975. Identification of *Anisakis* larva (I) as *Anisakis simplex* (Rudolphi, 1809, det. Krabbe 1878) (Nematoda: Ascaridata). J. Fish. Res. Board Can. 32: 29–32.

Adult parasitic nematodes, previously reared in vitro from *Anisakis* larvae (I) from herring, mackerel, and Norway haddock from the North Sea, are compared with recent descriptions of valid species and identified as *Anisakis simplex* (Rudolphi, 1809, det. Krabbe 1878).

PIPPY, J. H. C., AND P. VAN BANNING. 1975. Identification of *Anisakis* larva (I) as *Anisakis simplex* (Rudolphi, 1809, det. Krabbe 1878) (Nematoda: Ascaridata). J. Fish. Res. Board Can. 32: 29–32.

Des nématodes parasites adultes, élevés in vitro à partir de larves d'*Anisakis* provenant de harengs, maquereaux et aiglefins de Norvège capturés dans la mer du Nord ont été comparés avec de récentes descriptions d'espèces valides et identifiés comme étant *Anisakis simplex* (Rudolphi, 1809, det. Krabbe 1878).

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LARVAL nematodes belonging to the genus *Anisakis* Dujardin 1845 have been described under a variety of names, many of which were undoubtedly incorrect. Notable among the more recent authors who have attempted to clarify the taxonomy of the larvae are Punt (1941), Baylis (1944), Johnston and Mawson (1945), and Dollfus (1953). However, it was not until Grainger (1959) succeeded in rearing the larvae to the preadult stage that they were positively identified as larvae belonging to the genus *Anisakis*. Subsequently, Berland (1961) identified two types of *Anisakis* larvae which probably belonged to separate species: the common form which he called *Anisakis* larva (I), and an unusual form from the opah, *Lampris guttatus*, which he named *Anisakis* larva (II). Otsuru et al. (1968) reported a third type of larva (*Anisakis* larva [III]) from the walleye pollock, *Theragra chalcogramma*. Larva (II) had a shorter ventriculus than did larva (I) (.52 mm vs. .74 mm) and it did not possess a tail spine. Larva (III) had a short ventriculus similar to that in larva (II) but it possessed a tail spine similar to that of larva (I). Punt (1941) suggested that only one species was represented among his collections of larvae and several authors, such as Yamaguti (1935), Grainger (1959), Kagei (1969), and Oshima (1972) have expressed the opinion that the most common larvae are *Anisakis simplex*. However, positive identification of the *Anisakis* larvae could not be made until rearing to the adult stage in the laboratory became possible and the resulting adults compared with descriptions of recognized species.

Van Banning (1971) successfully reared larvae from herring (*Clupea harengus*), mackerel (*Scomber scombrus*), and Norway haddock (*Sebastes marinus*). However, he did not study the morphology of the adults he cultured and simply referred to them as *Anisakis marina* (Linnaeus, 1767). This identification was based on the proposal by van Thiel (1966) that all adult species of *Anisakis* in sea mammals in the North Sea and South Atlantic belong to the same species, *A. marina*, and that the specific name for the larvae in herring should therefore be *A. marina*. However, Khalil (1969) rejected van Thiel's proposal because he did not provide any evidence in support of his view. Davey (1971) recognized three valid species of *Anisakis*, (*A. simplex* (Rudolphi, 1809, det. Krabbe 1878), *A. typica*

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TABLE 1. Summary of morphometric data (in millimeters) of *Anisakis* larva infecting Atlantic herring (*Clupea harengus harengus*) from the North Sea, 1969. (N = number of observations; R = range; $\bar{x}$ = arithmetic mean; SD = standard deviation; CV = coefficient of variation expressed as percent.)

	N	R	$\bar{x}$	SD	CV
Total length	23	16.11–22.49	19.69	2.32	11.78
Diameter[a]	22	0.42–0.56	0.49	0.03	6.12
Anterior end to nerve ring	25	0.120–0.379	0.315	0.058	18.41
Length of esophagus	20	1.81–3.97	2.70	0.43	15.93
Length of ventriculus	20	0.58–0.98	0.78	0.13	16.67
Width of ventriculus[b]	21	0.089–0.304	0.204	0.050	24.51
Length of tail[c]	24	0.100–0.201	0.136	0.028	20.59
$\frac{\text{Total length}}{\text{Diameter}}$	22	32.15–53.55	40.39	7.83	19.39
$\frac{\text{Total length}}{\text{Length of esophagus}}$	20	6.12–12.46	7.51	1.36	18.11
$\frac{\text{Total length}}{\text{Length of tail}}$	24	96.26–203.82	150.40	31.37	20.86

[a]Determined at midpoint of body.
[b]Determined at midpoint of ventriculus.
[c]Length of tail determined from a lateral viewpoint; measurements were made from a curved line following the cuticle from the tip of the tail (excluding the tail spine) to the anterior lip of the anus.

(Diesing, 1860), and *A. physeteris* Baylis, 1923) and rejected van Thiel's "*marina*" because it depended on acceptance of the identity of *Gordius marina* as the larval stage of *A. simplex*. Van Banning's (1971) study could not, therefore, be considered as having solved the problem of the identity of the larvae. The purpose of the present study was to 1) determine the type of larvae used by van Banning and 2) present a specific identification of the adults reared by him.

Larval *Anisakis* were first recognized as potential human pathogens in Holland in 1955 (van Thiel et al. 1960) and infections with the larvae became known as anisakiasis. From 1955 to 1967, 149 proven cases of anisakiasis were reported from the Netherlands (Polak and Kampelmacher 1966; Bijkerk 1969). Similar cases have been identified in Norway (Davey 1972) and several hundred cases have been reported from Japan (Okumura 1967). The public health aspects of the larvae in herring have been reviewed by Davey (1972). Larvae involved in human anisakiasis are morphologically similar to Berland's *Anisakis* larva (I) (Okumura 1967). Specific identification of the larvae concerned will enable determination of the natural definitive hosts of the adult populations of the species.

Methods

A subsample of 25 larvae from van Banning's (1971) in vitro cultures were selected for morphological and morphometric examination. These originated from herring caught in the North Sea. They were frozen while in the culture medium, thawed, examined, and photographed, and all measurements except the distance from the anterior end to the nerve ring were obtained from projected images of the negatives. The distance of the nerve ring was measured immediately after thawing with the aid of a measuring eyepiece. Adults from van Banning's experiments were selected on the basis of condition and visibility of taxonomically important features; five males and five females were selected for detailed study. They were fixed in 70% ethanol and cleared in lactophenol or pure glycerine before examination. Taxonomically important structures in the adults were drawn with the aid of a camera lucida and measurements obtained from the drawings. The location of the vulva in the females was determined by dissection. En face views were prepared in glycerine jelly.

Results and Discussion

LARVAE

Morphology and morphometry (Table 1) of the larvae conformed with data given by Punt

TABLE 2. Spicule measurements of five specimens of *Anisakis* reared in vitro by van Banning (1971).

Length of worm (*mm*)	Length of spicule		Ratio
	Right (*mm*)	Left (*mm*)	
20	0.51	0.66	1:1.29
28	–	1.37	–
34	0.93	1.23	1:1.32
45	1.38	1.59	1:1.15
55	1.54	2.01	1:1.31

(1941) for *Anisakis* sp. larvae from thirteen species of marine teleosts. The shape of the ventriculus and the presence of a tail spine conformed with those of Berland's *Anisakis* larva (I).

ADULTS

Observations were based on five male and five female specimens. Only features of taxonomic importance are considered in detail.

Males — The specimens measured 36 (20–55) mm long (Table 2). Each lip carried a bilobed anterior projection and a dentigerous ridge on the inner surface. The dorsal lip carried two double papillae while the ventrolateral lips each had one such papilla. The ventriculus was either slightly sigmoid or folded upon itself. Spicules were slightly curved and unequal, the ratio of the length of the right to the left spicule being 1:1.26 (range 1:1.15–1:1.32; Table 2). Four pairs of postanal papillae were present in all specimens. One specimen had two pairs of adanal papillae while four specimens had four pairs each.

Females — These were generally larger than the males, 64 (50–80) mm long, and had similar cephalic characteristics. The vulva was at the midpoint of the body.

Davey (1971) concluded that three taxonomic characteristics of adults of the genus were the relative and absolute sizes of the spicules, the number and arrangement of the caudal papillae, and the position of the vulva. He noted that the lip morphology was similar for the three species he recognized and that variations in the overall contours of the lips were minor. The ratio of the length of the right to the left spicule of three of the specimens examined here was within the range cited by Davey for *A. simplex* (1:1.17–1:2.35) while the ratio of the remaining one (1:1.15) was greater than that for *A. physeteris* (1:1.12). However, it is very unlikely that this specimen was *A. physeteris* because the lengths of the spicules (1.38 and 1.59 mm) were much greater than the maximum size cited for *A. physeteris* (0.4 mm). Several of the spicules examined here were shorter than those reported by Davey for *A. simplex* and *A. typica* (Table 2). However, Davey noted that in *A. simplex* shorter worms tended to have shorter spicules. As most of the present specimens were shorter than Davey's material it is presumed that the spicule size would be less. Thus, their shorter spicules do not preclude identification as *A. simplex* (Fig. 1).

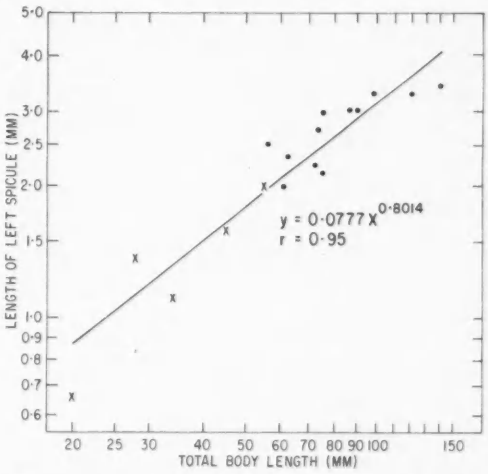

FIG. 1. Relationship of the length of the left spicule to the body length of the worm plotted on a double logarithmic grid. X = specimens reared in vitro (Table 2). ● = specimens of *Anisakis simplex* from a single host, *Orcinus orca* (data from Davey 1971).

The number and arrangement of the caudal papillae of the cultured specimens conformed with Davey's description of *A. simplex* but differed from *A. typica*, which has three pairs of papillae near the tip of the tail and from five to eight pairs close to the anus, and from *A. physeteris*, which has only one or two pairs of papillae (which may be double) and three rows of tiny denticulations close behind the anus.

The position of the vulva was similar to that of both *A. simplex* and *A. typica* but differed from that of *A. physeteris* in which it is found in the anterior third of the body.

Conclusion

It is concluded that the adults reared by van Banning from *Anisakis* larva (I), were *A. simplex*. We conclude that *Anisakis* larvae (I) in fish in

the North Sea belong to the species *A. simplex*. If *Anisakis* larva (I) represents one and only one of the three recognized species of *Anisakis*, all reports of these larvae in marine and anadromous fishes refer to *A. simplex*. In this case, the nematode responsible for most, if not all, human infections would be *A. simplex*.

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Growth, Metabolism, and Optimal Swimming Speed of a Pelagic Fish[1]

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WARE, D. M. 1975. Growth, Metabolism, and optimal swimming speed of a pelagic fish. J. Fish. Res. Board Can. 32: 33–41.

Ivlev's (1960) study of young bleak (*Alburnus alburnus*) is reanalyzed to determine whether or not the routine swimming speeds of planktivorous fishes could have evolved to maximize some obvious measures of biological performance – namely the growth rate, the growth efficiency, or the growth efficiency arising from a particular food ration. Each criterion had a maximum value at a different swimming speed. But for bleak the observed speed of 107 m h^{-1} was closest to the one, 111 m h^{-1}, which maximizes growth. The possible evolutionary significance of this finding is discussed.

New calculations based on Ivlev's work indicate that the field metabolism of young, actively growing fish may be closer to 3 times the standard metabolic rate, rather than the factor of 2 suggested by Winberg (1956).

WARE, D. M. 1975. Growth, metabolism, and optimal swimming speed of a pelagic fish. J. Fish. Res. Board Can. 32: 33–41.

Nous avons réanalysé l'étude faite par Ivlev (1960) sur de jeunes ablettes (*Alburnus alburnus*), en vue de déterminer si oui ou non les vitesses de nage routinières de poissons planctonophages ont pu avoir évolué afin de maximiser quelque mesure évidente de performance biologique – nommément rythme de croissance, efficacité de croissance ou efficacité de croissance résultant d'un régime alimentaire particulier. Chaque critère a une valeur maximale à une vitesse de nage différente. Mais pour des ablettes, la vitesse observée de 107 m h^{-1} est celle qui se rapproche le plus de la vitesse, 111 m h^{-1}, qui maximise la croissance. Nous examinons la signification évolutive possible de cette constatation.

De nouveaux calculs, basés sur le travail d'Ivlev, indiquent que le métabolisme dans la nature de jeunes poissons croissant activement peut être proche de 3 fois le taux métabolique standard, plutôt que le facteur de 2 suggéré par Winberg (1956).

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THE energetic cost of swimming by fish has received considerable attention from physiologists, but has seldom been treated from an ecological viewpoint. This distinction is relevant because the cost of locomotion contributes to the overall metabolic load, thereby affecting the potential growth response and presumably fecundity. Recognizing that routine energy expenditures are difficult to calculate for wild fish, Winberg (1956) suggested as an approximation that field metabolism was roughly twice the standard level measured under appropriate experimental conditions. Although this supposition has been indirectly supported (Mann 1967), for the most part the evidence is still circumstantial. This generalization has been criticized by Warren and Davis (1967), who present cogent arguments suggesting why the metabolism of fish subject to different nutritional regimes is unlikely to be a constant multiple of the standard rate.

Besides such areas of practical concern, swimming speeds during routine activities such as feeding and migration are of theoretical importance. Kerr (1971), for instance, calculated the metabolism of wild trout by assuming that natural selection operates to maximize the growth efficiency: food intake ratio. Similar applications of optimal design principles have been discussed in detail by Rosen (1967), but he was careful to point out that since the decision as to what is being optimized is purely subjective it is easy to overlook alternative solutions which may be more compatible with evolutionary theory.

The purpose of this account is to examine the effect of swimming speed[2] on several biological

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[2]The term swimming speed, unless otherwise indicated, refers strictly to the average velocity of a fish during feeding and not to the basal speed often required to counteract negative buoyancy.

performance criteria related to the growth and metabolism of a planktivorous fish. Several implications of this approach are then evaluated by reviewing Ivlev's (1960) work on juvenile bleak (*Alburnus alburnus*).

Cost of Feeding

Winberg (1956) and more recently Paloheimo and Dickie (1966) recommend using the mass balance equation for energetics studies:

$$pI' = T' + G' \quad (1)$$

where I' = daily food ration, cal day^{-1}
T' = total metabolism, cal day^{-1}
G' = growth, cal day^{-1}
p = assimilation factor

The major energy transformations summarized by this simplified scheme can be clarified by expanding the metabolism and food ingestion terms as follows:

Taking the latter term first, consider a small planktivore feeding while swimming at a speed of v (m h^{-1}). In 1 h it will consume food at a rate I (cal h^{-1}) which depends partly upon its searching capabilities, and the abundance and size composition of the plankton. (For simplicity an evenly distributed food supply of uniform size is assumed.) In general there is ample evidence (Holling 1966) to show that the relationship between the feeding rate and food concentration (ρ, cal m^{-3}) can be described by an equation of the form:

$$I = \frac{\gamma v \rho}{1 + \gamma v \rho h} \quad (2)$$

where γ (m^2) indicates the area successfully searched (probability of food capture × the cross-sectional area of the visual field), and h (h cal^{-1}) = time required to capture and consume one calorie of food.

Since γ is independent of the swimming speed equation 2 implies that the rate of food consumption will rise asymptotically as v increases. Any apparent energetic advantage gained by increasing the velocity of search, however, is obviously counterbalanced by the metabolic term in equation 1; for it is well known that the cost of locomotion (E, cal h^{-1}) is proportional to some power of the swimming speed:

$$E = z + \alpha v^{\beta} \quad (3)$$

Here standard metabolism (z, cal h^{-1}) is assumed to be a fixed cost and is included in equation 3 for convenience, whereas α and β are empirical constants indicating the additional cost of swimming at various speeds.

Another factor contributing to the total metabolic load is the so-called specific dynamic effect of food (SDA). Brody (1945) and Kleiber (1961) discuss the history of this concept in some detail but for our purposes it is sufficient to note that SDA represents an entropic tax paid during food conversion. In practice the magnitude of this effect is difficult to estimate since it depends partly upon the nutritional content of the diet, and the relative proportions of metabolizable lipids, carbohydrates, and proteins ultimately used as metabolic fuel. Despite this complication if SDA and the loss of chemical energy in the "urine" are assumed to be proportional to the ration (i.e. sI), then total metabolism (T, cal h^{-1}) can be estimated by adding an additional term to equation 3:

$$T = sI + z + \alpha v^{\beta} \quad (4)$$

After the calorific expense of handling a meal is deducted from the metabolizable energy in the food, the resulting difference must appear as either a positive or negative change in body substance. Hence growth (G, cal h^{-1}) is calculated by combining equations 1, 2, and 4 as follows:

$$G = \tau \left[\frac{\gamma v \rho}{1 + \gamma v \rho h} \right] - [z + \alpha v^{\beta}] \quad (5)$$

where τ signifies the portion of the ration ultimately recovered as net energy, i.e. $\tau = p - s$.

Performance Criteria

According to current evolutionary ideas at least three measures of biological performance can be deduced from the foregoing equations. (Throughout this discussion the term "growth" refers to the total reserve of surplus energy regardless of whether it is stored as somatic or reproductive tissue.) To begin with, it seems reasonable to suppose that in some circumstances there will be a strong selective advantage for individuals which maximize their growth rate. Although this hypothesis is attractive it is not, of course, the only possibility. Alternative arguments could be developed to show when it would be favorable for individuals to maximize their growth efficiency — usually defined as $K = G/I$ — or their growth efficiency per unit ration, i.e. K/I (Kerr 1971). Note that the latter postulates, by implying food is handled conservatively, bear entirely different implications from the concept of optimal growth, which assumes that fish operate within their

physiological and environmental constraints to maximize their energy reserves.

Apart from this difference, however, all three postulates presuppose that swimming speeds have evolved like other behavioural characteristics to optimize some measure of performance. Operationally this hypothesis can be evaluated by calculating the swimming speeds which maximize each of the preceding indices, and comparing them with the observed speed of wild fish to determine if it maximizes one of the three alternative performance criteria. Ivlev's (1960) extensive study of bleak will serve as a case in point.

Metabolism and Growth of Bleak

Ivlev (1960) developed a metabolic scheme similar to the one outlined above and tested it by gathering appropriate field and experimental data on the feeding, growth, and respiration of post-larval bleak. The live fish weighed an average of .25 g. Although he failed to mention their average length, we should not be far wrong in assuming they were about 3 cm long.

According to Ivlev a natural population of bleak was accidently discovered in a hatchery pond. Apparently the fish were of uniform size and age, and he calculated that each fish gained about 0.0067 g day^{-1} or roughly 5 cal day^{-1} over an 18-day period. *Cyclops* was the primary food source: during the study period there were approximately 73,455 copepods m^{-3} or 808 cal m^{-3}.

For his analysis, Ivlev used an earlier estimate of foraging velocity where bleak swam about 107 m h^{-1}; in this case the food supply was approximately 1000 cal m^{-3}. Also, to determine the cost of foraging, he measured the metabolism of several fish at rest and at two forced swimming speeds. The latter measurements were corrected to include the postexperimental oxygen debt. Equation 3 can be evaluated for bleak from his data if an oxycalorific factor of 4.77 cal/ml O_2, is assumed and if swimming speed is expressed in m h^{-1}:

$$E = .572 + .00029\, v^{1.79} \qquad (6)$$

Similarly, Ivlev's results describing the feeding rates of captive fish exposed to different food concentrations can be recalculated to conform with the notation used in equation 2; the result is:

$$I = \frac{.000055\, v\rho}{1 + .00000225\, v\rho} \qquad (7)$$

with the proviso that I must assume a value less than, or equal to a maximum ingestion rate of 15 cal h^{-1}.

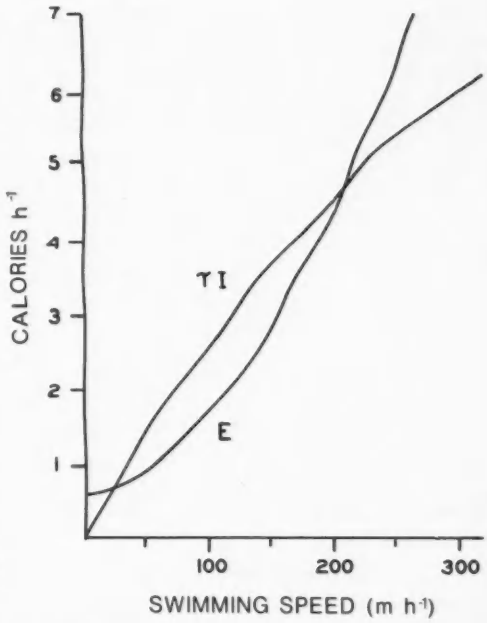

Fig. 1. Net food intake (τI) and cost of swimming (E) at different speeds. Values for the food concentration and τ were taken as 808 cal m^{-3} and .70, respectively.

Optimal Swimming Speed

The solutions to equations 6 and 7 as functions of swimming speed are shown in Fig. 1. The energy difference between the net food intake and expenditure equations indicates that bleak can operate with an energy surplus (once metabolic costs are deducted) so long as their speed varies between 25 and 210 m h^{-1}. Velocities outside these limits could not be maintained for a prolonged period of time simply because the costs of feeding and metabolism would exceed the amount of useful or net energy in the food.

The effect of swimming speed on the potential growth of bleak was evaluated by substituting equations 6 and 7 into 5, and by setting $\tau = .70$ (Table 1; Appendix). As shown in Fig. 2, the positive phase of the growth curve as well as the alternative performance criteria lay within the range in speed indicated above, and their respective maximum values occurred in the following order:

$$[K/I]_{max} = 40 \text{ m h}^{-1}$$
$$K_{max} = 69 \text{ m h}^{-1}$$
$$G_{max} = 111 \text{ m h}^{-1}$$

Since there will usually be some uncertainty concerning the true value of τ, Fig. 3 demonstrates that the optimum speeds for G_{max} and $[K/I]_{max}$ increase and decrease, respectively, depending upon the coefficient of food extraction used in the simulation, while for all practical purposes K_{max} remains unchanged. What is important here is that the observed speed of "wild" bleak (107 m h^{-1}) tends to maximize their growth rate if τ assumes a value anywhere between .65 and .75.

TABLE 1. Parameter values recalculated from Ivlev (1960).

Parameter	Value
α	.00029
β	1.79[a]
ρ	808 cal m^{-3}; 1.102 g m^{-3}
h	.041 h cal^{-1}
p	.86
s	.16
τ	.70
z	.572 cal h^{-1}
γ	.000055 m^2

[a]Ivlev's value of 1.81 appears to be an error.

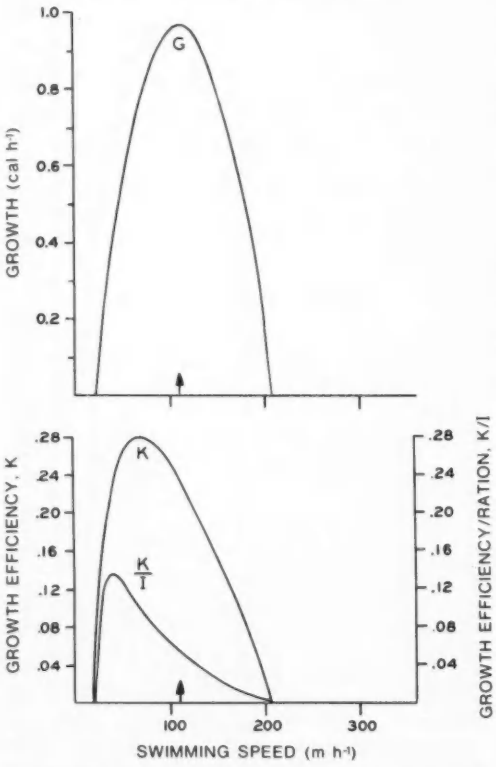

FIG. 2. Relation between the growth rate, growth efficiency, and growth efficiency/ration at different swimming speeds. The simulated food concentration was 808 cal m^{-3}. The arrows indicate the observed speed of wild bleak (107 m h^{-1}).

It follows from the foregoing considerations that the optimal speeds also depend on the ambient food concentration. Such an effect is illustrated in Fig. 4. Here the performance criteria attain maximum values at the same velocity when the food supply is slightly greater than the limiting concentration of 450 cal m^{-3}. Growth ceases at this point because the metabolic expenses of bleak consume all the energy they can ingest by continuous feeding. However, once foraging conditions improve beyond this threshold concentration the optimal speed for growth increases steadily until it reaches a peak of 154 m h^{-1} when $\rho = 3$ Kcal m^{-3}, whereas the optional speeds for K_{max} and $[K/I]_{max}$ decline monotonically. Figure 4 obviously considers an extreme set of circumstances as aggregations of plankton will seldom, if ever, exceed 3 Kcal m^{-3} in nature.

Revised Energy Budget

If bleak remain relatively quiescent between meals, then the daily cost of metabolism can be estimated by relating the hourly intake–expenditure equations to the measured growth increment, i.e. $G' = 5$ cal day^{-1}. In other words what we want is an expression describing how many hours t bleak must forage in order to grow G' cal day^{-1}. The answer, of course, is simply:

$$G' = tG - z\,(24 - t),$$

whence

$$t = \frac{G' + Z'}{G + z} \qquad (8)$$

where $Z' = 24\ z$ = standard metabolism in cal day^{-1}.

Solving equations 5, 7, and 8 for $\rho = 808$ cal m^{-3} and $v = 107$ m h^{-1}, we find:[3]

$$t = 12.1 \text{ h day}^{-1}$$
$$I' = tI = 48.3 \text{ cal day}^{-1}$$
$$T' = pI' - G' = 36.6 \text{ cal day}^{-1}$$

[3]The main assumption made in calculating t is that the variance in the density-distribution of plankton is $\leqslant$ the $\bar{x}$ number m^{-3}. It is an easy matter to show that equation 8 can substantially overestimate foraging time if the amount of time bleak spend in a volume of water is proportional to the food concentration.

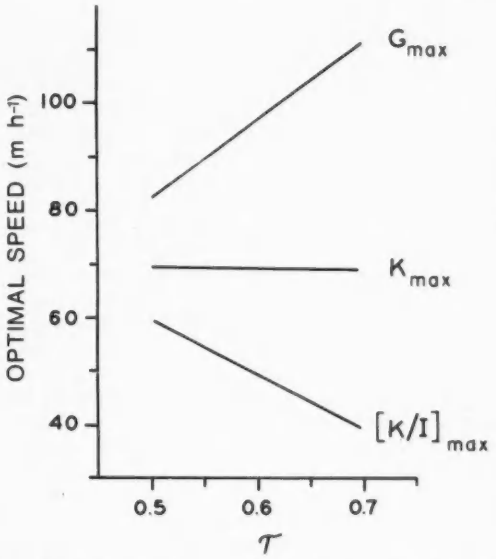

FIG. 3. Change in the optimal speed as a function of the net efficiency of food conversion (τ).

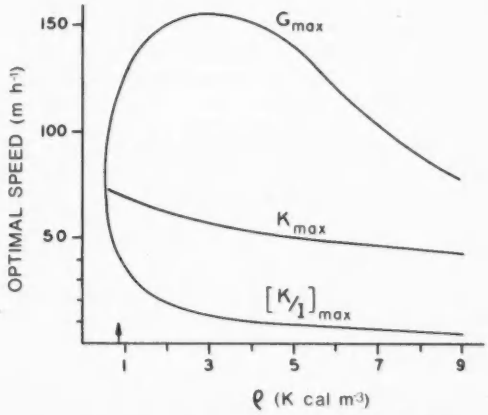

FIG. 4. Change in the optimal speeds with food concentration (ρ). The arrow indicates the apparent density of plankton (808 cal m^{-3}) in Ivlev's study.

Thus a ration of 48 cal day^{-1} is sufficient to cover the daily metabolic costs and a growth rate of 5 cal day^{-1}. From these figures one can also compute several other statistics: (i) the ratio of daily metabolism to standard is (36.6:13.73) = 2.67, (ii) the growth efficiency is (5:48.3) = 0.10, and (iii) the daily cost of foraging is 15.0 cal which represents about 31% of the ingested energy.

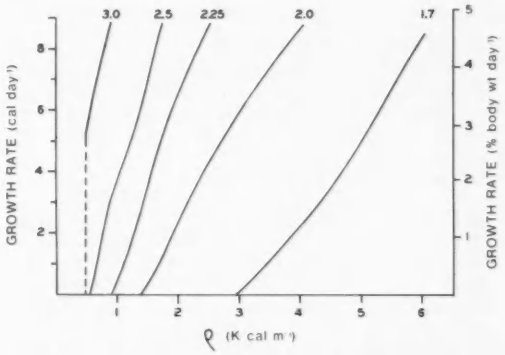

FIG. 5. Isopleths showing the relation between the daily growth rate, food density, and the metabolic rate. The figures beside each curve express the daily metabolism as a multiple of the standard rate. The simulations assume that bleak attempt to maximize their growth rate by foraging at the appropriate speed for each food concentration (see Fig. 4). The dashed line marks the limit to metabolism; presumably bleak cannot move to the left of this line, even if they forage continuously for 24 h.

Ivlev calculated that bleak could satisfy their growth rate by foraging 9.6 h day^{-1}, during which time 38.3 cal of food would be ingested and 25.6 cal day^{-1} would be consumed by metabolism. According to his figures the daily metabolic rate is 1.86 times the standard, while the growth efficiency is 0.13. The discrepancy between these calculations and those obtained here arises because Ivlev assumed a food conversion coefficient of 0.8. Frankly, this value seems too optimistic and surely overestimates the fraction of the ration recovered as net energy (Appendix).

Fortunately the data for bleak are sufficiently detailed to allow us to check the validity of Winberg's rule concerning the metabolism of rapidly growing fish in nature. If the daily metabolism of bleak is calculated for a variety of hypothetical growth rates and food densities, the level of metabolism (expressed as multiples of the standard rate) required to support a growth rate of, say, 3% of the body weight day^{-1} turns out to be about 3 times standard under usual feeding conditions (Fig. 5). However, when the food supply is better than average a multiplier of 2–2.5 times standard seems to yield a more reasonable estimate. Whatever the case, it is clear

that the use of a constant multiplier is not acceptable because T′ can vary between at least 2 to 3 times standard. Though Winberg recognized that field metabolism could differ by this amount, curiously, he still recommended a factor of two.

Discussion

In the end one is forced to live with the fact that many of the conclusions drawn from bioenergetics studies of natural populations rest upon a foundation of questionable assumptions. Perhaps the greatest uncertainty at this time is whether the rate of food intake continues to rise asymptotically as a function of speed (γ = constant); or if it in fact reaches an apex at some intermediate velocity and then declines ($\gamma \neq$ constant). If the net food intake curve shown in Fig. 1 is not asymptotic then the optimal speed for each criterion will decline, but should retain the same relative order with $(K/I)_{max}$ occurring at the lowest speed, followed by K_{max} and G_{max}.

Another somewhat less annoying problem is that the method for calculating the optimal speeds also depends upon choosing an appropriate value for τ. Opinions on food conversion efficiencies have changed considerably in recent years. For instance, Winberg (1956) suggested that 85% of the energy in most natural foods is assimilated. For some reason he ignored the calorigenic effect of metabolism and went on to conclude, after incorporating a small correction factor to cover the loss of chemical energy in the urine, that 80% of the ingested ration is recovered as net energy. In his later work Ivlev (1960), presumably acknowledging Winberg's advice, adopted an 80% conversion factor.

Most recent estimates of conversion efficiencies have either been derived indirectly from energy budgets by difference, or else rely on rather tenuous assumptions about the metabolic costs of starved and fed fish. Both methods probably tend to overestimate the cost of SDA. By contrast, Muir and Niimi (1972) obtained one of the more reliable values for SDA by measuring the increase in the metabolic rate of aholehole (*Kuhlia sandvicensis*) following a meal. Unfortunately, they failed to determine the calorific content of the food, but by making a reasonable guess they concluded that SDA accounted for 16–19% of the ingested energy, making it comparable to the value used here (Appendix). As a rule, then, though the efficiency of food conversion is affected by a number of factors (Warren and Davis 1967), we should not be far wrong in assuming that 65–75% of the energy ingested by young fish can be apportioned for growth or physiological work. This approximation may not hold for older fish, however, where presumably more of the dietary protein is consumed to cover the routine costs of living; during ontogenesis τ could decline and eventually assume a value as low as .6.

Considering the current interest in the concepts of *K* and *r* selection it is relevant to find that the foraging speed of bleak maximizes their growth rate. Pianka (1972) recently proposed that one would expect a positive relationship between the amount of energy expended to produce an individual offspring and its fitness. All else being equal, he, as well as others, argue that *K* selection (selection for competitively fit progeny) ought to occur under conditions of intense competition. In this case, the reproductive members of the population must expend a greater amount of energy to produce a single fit offspring, thus *K* selected individuals must invariably have a low fecundity. Conversely, *r* selection (selection for early reproduction and high fecundity) occurs when competition is reduced and there is less need to produce progeny with high competitive abilities. Such *r*-selected individuals can therefore use the energy allocated to reproduction for producing comparatively more offspring.

Though admitting this scheme is oversimplified, Pianka suggests that the basic difference between *r* and *K* selection lies in the amount of energy expended per progeny. From our point of view regardless of whether an individual is exposed to intensive *r* or *K* selection it seems reasonable to assume that natural selection will favor organisms which maximize their growth. In the case of *r* selection there would seem to be two advantages to growing rapidly: (i) the age of maturity is often size-dependent, hence fast growing individuals will mature at an earlier age, and (ii) since fecundity tends to increase with increasing body size, the same individuals (if they live as long as their competitors) will produce more progeny in their lifetime. *K* selected organisms, on the other hand, are likely to spend more of their limited time and energy on various competitive activities (Pianka 1972). Here again, it would appear advantageous to maximize the rate of growth for such individuals will, by definition, accumulate more net energy per unit searching time than competitors following different tactics. As an example, suppose some bleak were to swim at a speed which maximized their growth efficiency. At that speed they will grow at a suboptimal rate (Fig. 2) which, in turn, could place

them at a disadvantage relative to faster growing conspecifics regardless of the intensity of competition.

At present it is a matter of conjecture whether swimming speeds have evolved on an ecological time scale and thus are relatively invariant, or if they are controlled to exploit spatial and temporal variations in the food supply. The latter possibility is not entirely speculative as Magnuson (1967) found that skipjack tuna increased their swimming speed above the typical or basal level when food extracts were injected into the water. If the arguments for maximizing growth are applicable to natural populations then one can predict that the foraging speed of a species, in equilibrium with its food supply, ought to change according to the food concentration (Fig. 4). Similarly, a more highly responsive predator, like tuna, might even alter its swimming speed in space and time or both depending on the local feeding opportunities.

Although these possibilities emphasize the ecological significance of swimming speeds, the most important aspect of this reanalysis has been in showing that empirically determined factors, affecting the growth of natural populations, can be used to assess optimality criteria. Indeed, it appears from the increasing interest in this area that the principle of optimum design is destined to play a fundamental role in modern population theories.

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Appendix

CALCULATION OF τ

A value for τ was computed partly from Ivlev's findings and partly by analogy with other studies. In the following discussion I have used the nomenclature recommended by Kleiber (1961).

To begin with, we know that bleak exposed to a food supply of 808 cal m^{-3} will ingest 3.99 cal h^{-1} at a metabolic cost of 1.81 cal h^{-1}. Because the chemical composition of the diet affects assimilation and conversion efficiencies, an average ash-free proximate composition for copepods was recalculated from Raymont's (1963) data (Appendix Table A I). Next, the energy ingested as lipids and carbohydrates was converted to net energy by applying representative assimilation (Phillips 1969) and SDA factors (Brody 1945) for each fraction.

Winberg (1956) stated that the dietary fats and carbohydrates of growing fish are probably used to support metabolism. Hence the amount of protein diverted to cover the residual metabolic costs was estimated as follows:

After metabolism the nonprotein fraction of the ration will yield .66 cal h^{-1}, leaving a deficit of (1.81–.66) = 1.15 cal h^{-1}. Kleiber (1961) notes that 16% of the primary heat of combustion for proteins is lost in the urine when the by-product of metabolism is urea. As a rule freshwater teleosts excrete nitrogen

TABLE A I. Revised energy budget for bleak (*Alburnus alburnus*).

Fraction	Composition	Ingested cal h^{-1}	Assimilation factor	Digested cal h^{-1}	Urine cal h^{-1}	Metabolizable cal h^{-1}	SDA Factor	SDA cal h^{-1}	Net cal h^{-1}
Protein	.755	3.012[a]	0.90	2.711	0.068[b]	2.643	0.30	0.493[c]	2.150
Fat	.202	0.806	0.85	0.685	–	0.685	0.13	0.089	0.596
Carbohydrate	.042	0.168	0.40	0.067	–	0.067	0.06	0.004	0.063
TOTAL		3.986		3.463	0.068	3.395		0.586	2.809

[a]This column of figures does not account for the disparate heats of combustion of proteins, lipids and carbohydrates.
[b]Indicates urea produced from metabolized protein = .04 × 1.711 cal h^{-1}.
[c]Indicates energy lost through SDA of metabolized protein = .30 × 1.643 cal h^{-1}.

predominantly as ammonia; hence, the loss of chemical energy should be considerably less than 8% of the digested protein energy — say 4%. Finally, if we assume an additional 30% loss of metabolizable energy through SDA (Brody 1945), then

$$1.15/(.96 \times .70) = 1.71 \text{ cal h}^{-1}$$

of the digested protein pool must be used as a metabolic fuel. A complete set of computations showing the probable fate of the diet is summarized in Appendix, Table A I. According to these expectations we arrive at the following values:

$$\tau = \frac{\text{Net energy}}{\text{Ingested energy}} = .70$$

$$p = \frac{\text{Digested energy}}{\text{Ingested energy}} = .86$$

$$s = \frac{\text{Energy lost in urine + SDA}}{\text{Ingested energy}} = .16$$

Age and Growth of Dogfish *Squalus acanthias* in British Columbia Waters

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KETCHEN, K. S. 1975. Age and growth of dogfish *Squalus acanthias* in British Columbia waters. J. Fish. Res. Board Can. 32: 43–59.

Ages of dogfish have been determined from markings on the second dorsal spine by a technique that enables use of badly worn spines from relatively large fish to correct for the tendency to underestimate age. While the technique may have led to slight overestimation of age, particularly of dogfish from Hecate Strait, there is some corroborating evidence for the Strait of Georgia drawn from length-frequency distributions, sizes of fish in relation to reproductive stages, and assumptions about the average annual net uptake of mercury. It is tentatively concluded that the growth curve for females, expressed in terms of the von Bertalanffy equation, has parameters of $K = 0.048$, $L_\infty = 125.3$ cm, and $t_0 = -4.88$ yr. Parameters suggested for males are: $K = 0.070$, $L_\infty = 99.8$ cm, and $t_0 = -4.70$ yr. The implication emerging from these results is that females and males on the average take 23 yr and 14 yr, respectively, to reach maturity.

KETCHEN, K. S. 1975. Age and growth of dogfish *Squalus acanthias* in British Columbia waters. J. Fish. Res. Board Can. 32: 43–59.

Nous avons déterminé l'âge d'aiguillats communs à partir de marques sur la deuxième épine dorsale, nous servant d'une technique qui permet d'utiliser les épines très usées de poissons relativement grands et de corriger la tendance qui existe par ailleurs à sous-estimer l'âge. Il est possible que la méthode ait causé une surestimation de l'âge, surtout chez les aiguillats du détroit d'Hécate. Par contre, chez ceux du détroit de Géorgie, on a pu confirmer l'âge par la répartition des fréquences de longueur, la taille du poisson en relation avec les stades reproducteurs et par des hypothèses quant à l'absorption nette annuelle moyenne de mercure. Nous concluons provisoirement que la courbe de croissance des femelles, exprimée dans les termes de l'équation de von Bertalanffy, a des paramètres de $K = 0.048$, $L_\infty = 125.3$ cm et $t_0 = -4.88$ ans. Les paramètres suggérés pour les mâles sont: $K = 0.070$, $L_\infty = 99.8$ cm et $t_0 = -4.70$ ans. L'implication qui émerge de ces résultats est que les femelles et les mâles prennent, en moyenne, 23 et 14 ans respectivement à atteindre la maturité.

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KNOWLEDGE of the age and growth of sharks, as compared with that of teleost fishes, is scarce because of their general lack of cycloid or ctenoid scales, otoliths or other hard parts of the body customarily used for age determination. There are, however, two shark families that are distinguished by possession of a sharp, hard spine projecting from the body along the anterior margin of both dorsal fins. One of these families (Squalidae) contains the common spiny dogfish *Squalus acanthias*.

Holden and Meadows (1962) quoting Markert (1896) noted that the exposed portion of the spine consists of a hard polished enamel outer layer overlying a thin layer of pigment, three layers of dentine, and a central pulp cavity. There is a more or less regular series of dark bands of pigment associated with ridges in the enamel which may be indicative of annual changes in growth and hence may be useful in determining the age of dogfish.

Relatively few studies of age and growth have been reported on dogfish, the principal contributions being those of Kaganovskaia (1933) for the northwestern Pacific, Bonham et al. (1949) for the northeastern Pacific (Washington coast), Aasen (1961) and Holden and Meadows (1962) for the northeastern Atlantic, and Templeman (1944) and Hisau and Albert (1947) for the northwestern Atlantic.

The purpose of this paper is to present results of a critical examination of new material on age and growth for the northeastern Pacific, and to

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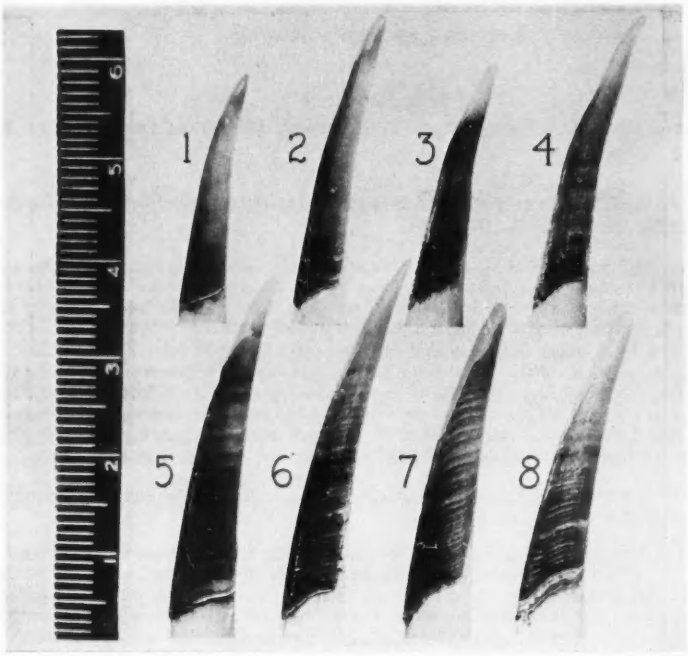

FIG. 1. Lateral view of second dorsal spines from female dogfish collected in Hecate Strait (scale in cm). Fish lengths and estimated ages: 1) 39 cm, 2 yr; 2) 69 cm, 16 yr; 3) 82 cm, 24 yr; 4) 89 cm, 31 yr; 5) 93 cm, 22 yr; 6) 104 cm, 43 yr; 7) 109 cm, 42 yr; 8) 113 cm, 46 yr (all but no. 1 and 2 with ages calculated as per technique described in text).

extend and reexamine preliminary work of Bonham et al. (1949), with special reference to the female of the species.

Materials and Methods

During March and June 1966 a roughly stratified sample of 445 second-dorsal spines from a wide range of sizes of dogfish was collected on various trawling grounds throughout Hecate Strait, B.C., with inclusion of a small number of specimens from Queen Charlotte Sound. To this collection was added a sample of 41 spines from fish captured in June 1956 on the Hecate Strait flats. In the Strait of Georgia, sampling was conducted during May 1971 in order to determine distribution and intensity of mercury contamination in dogfish. This study provided 200 specimens for age determination.

Collections of several thousand specimens for corroboration of age determinations were made in surveys of the "Gulf Islands" area of the Strait of Georgia between December 1969 and October 1973. Summaries of these surveys were reported by Smith (1970, 1972, 1973, and 1974) and Smith and Kristiansen (1970).

Criteria for Estimating Age

Spines were examined under a low power (×7) binocular microscope with direct lighting from above. No firm criteria were established for recognition and rejection of false checks or acceptance of those thought to be genuinely annual. The fact that many of the spines showed irregular spacing between supposed winter checks was usually ignored on the assumption that growth does not necessarily proceed in an orderly manner. Decision as to whether two closely spaced bands constituted two genuine winter checks or merely a "split" was left to the judgment of the reader. In other words, it was assumed that all reasonably distinct and complete bands were bona fide winter checks, whether irregularly spaced or not. The least distinct bands (broad and faintly colored) were usually those marking the first 5–7 yr of growth, while those for greater ages tended to be closely arrayed yet quite sharp and distinct (Fig. 1).

In contrast, Holden and Meadows (1962) took great care in their study of North Sea dogfish or "spur-dogs" (*S. acanthias*) to establish a number of criteria upon which to base their readings. Their greatest concern was to identify false rings, that is,

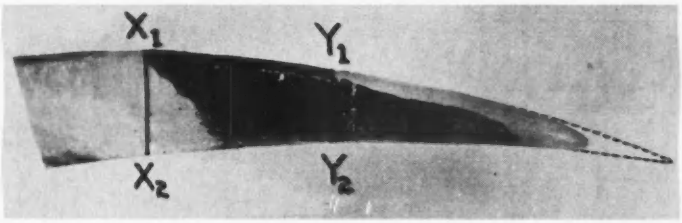

FIG. 2. Sketch of spine defining diameter of spine base X_1X_2 and diameter at point of no wearing, Y_1Y_2.
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within-year checks and split winter checks. They reported that the latter phenomenon was observable in a high percentage of cases. If indeed two closely spaced rings were mistakenly counted as one winter check and not as two true annuli, the tendency would be to underestimate age and overestimate growth rate. M. J. Holden (personal communication 1968) assumed that the pattern of growth in dogfish is a regular one, as in the case of many better-known bony fishes and that growth decreases exponentially with age. While this assumption may be perfectly valid for the dogfish of the North Sea, there is the inherent danger that age will be underestimated and that the results will lead to an asymptotic growth curve reflecting the reader's conscious or subconscious preconception of what the growth pattern should look like. This is not to deny that a judiciously standardized procedure for accepting or rejecting a ring as a bona fide annual check would provide more reliable results. However, thorough study of spines from northeastern Pacific dogfish revealed so much variability in the shape, spacing, and darkness of alleged winter checks that no confidence could be attached to a rigid set of criteria for age determination.

CRITERIA FOR REJECTION OF READINGS

The 445 specimens from Hecate Strait and Queen Charlotte Sound were examined by two readers (one the author) working independently of each other. The great difficulty experienced in ageing of dogfish is evident in that, of 410 readable spines, there was complete agreement in the reading of only 22%. Twenty-six percent differed by 1 yr and 16% by 2 yr, 29% by 3–6 yr and 7% by an even greater number. Added to this difficulty was the fact that the enamel on a substantial number of the spines of large dogfish was severely worn with consequent obliteration of annuli. Thus, though the readers may have agreed in their estimations of age, the true ages in such cases were probably much older.

In selecting readings for calculation of growth rate, attention was first directed to spines that showed little or no wear (the precise definition of a worn spine is given in the following section). Where the two readers were in agreement the reading was accepted for computation of growth rate. Where the estimated ages differed by 1 yr, the estimates of the readers were selected alternately. For readings that differed by 2 yr, the mean of the two readings was accepted. Those that differed by more than 2 yr (still considering just the unworn spines) were rejected from further analysis. To this point the procedure was more or less the same as that of Holden and Meadows (1962).

Holden and Meadows (1962) rejected all readings in which the disagreement was more than 2 yr and, in addition, rejected all readings from spines that appeared to have been worn down below the first annual ring. Bonham et al. (1949) simply selected those spines for which there was least disagreement and presumably rejected many of the broken or worn spines of large dogfish. Kaganovskaia (1933) indicated that spines which were difficult to read were rejected and that these were usually from fish of an estimated age in excess of 18 yr.

CALCULATION OF AGE FROM WORN SPINES

We have used a different approach from that of the above-mentioned authors in an effort to compensate for the bias that must occur if badly worn, probably old, spines are rejected out of hand. First, the thickness of the base of each unworn spine was measured with vernier calipers (precision 0.05 mm). In cross section the base of the spine is roughly triangular with the apex being the anterior edge. The altitude of this triangle was measured and for simplicity will henceforth be referred to as the "diameter." The "base" of the spine is indicated by the line X_1X_2 in Fig. 2.

Secondly, estimated ages from conception, determined for dogfish whose spines showed little or no wear (fish generally less than 70 cm in length[1]) and that met the ±2-yr criterion, were plotted against

[1]All lengths referred to in this paper are total lengths measured from the tip of the snout to the tip of the upper lobe of the caudal fin when depressed to align with the longitudinal axis of the fish.

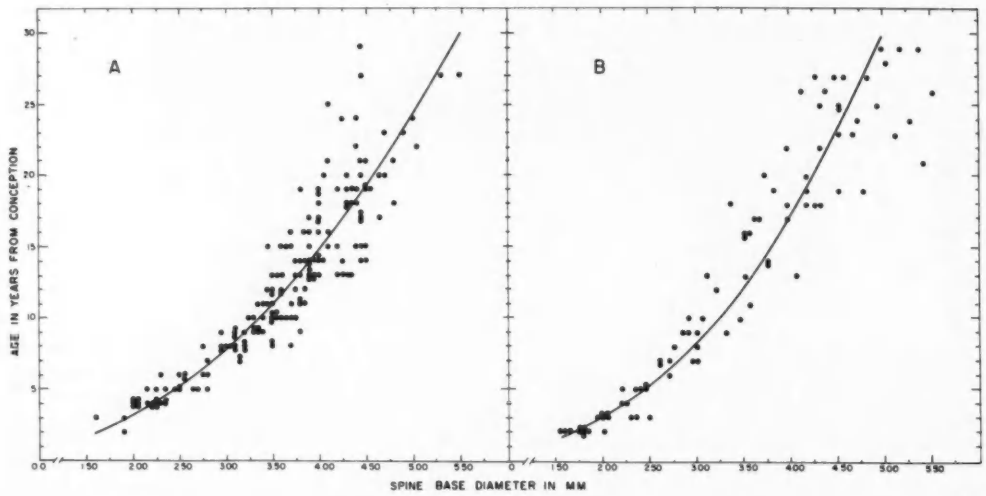

FIG. 3. Relationship of age of dogfish to diameter of base of second dorsal spine: A, Hecate Strait; B, Strait of Georgia.

spine base diameter as in Fig. 3A. As there was no visual indication of sex differences, the Hecate Strait data were pooled to yield a functional regression (Ricker 1973) expressed as

$$Y = 0.6907\ X^{2.2115}$$

where X is the spine base diameter in millimeters and Y is the estimated age in years from conception.

The criterion of wear was determined from the diameter of the spine at the most distal point of no wearing (NWP) on the anterior surface of the spine, namely, the diameter at Y_1Y_2 in Fig. 2. All spines whose Y_1Y_2 measurements were greater than 2.05 mm, i.e. the calculated average diameter of the spine base 1 yr after birth, were excluded from Fig. 3 (diameter at birth averages about 1.55 mm.)

For all worn spines, the number of growth rings observed between point X_1 on the base line and Y_1 on the NWP line were counted and recorded. To these were added the number of rings that should have been indicated on the leading edge or sides of the spine had it not been damaged by wear. To cite a specific example: spine no. 305 from an 89-cm female showed 28 rings (an average of two independent readings) between the base and the NWP line; the diameter at the latter point was 3.20 mm from which, according to Fig. 3A, age from conception was estimated as 9 yr (or 7 yr from birth). Thus the calculated complete age was 28 + 7 or 35 yr. In this way, maximum possible use was made of spines available from large dogfish. The method departs radically from that of Holden and Meadows (1962) and of Bonham et al. (1949), but it appears to be the only means of avoiding a bias that may lead to underestimation of age and overestimation of growth rate. Nevertheless, it is recognized that in trying to avoid underestimation of age, this technique runs the risk of accumulating errors of overestimation.

Spines collected from Strait of Georgia dogfish were subjected to the same treatment as that described above, except that the age readings are those of the author alone. After two independent readings, the ±2 criterion was applied to select the apparently complete readings, namely, those from spines on which the NWP diameter was no greater than 2.05 mm. This permitted construction of the curve shown in Fig. 3B, a functional regression, the equation of which is

$$Y = 0.5097\ X^{2.5480}$$

and from which the ages of older dogfish were estimated in the same manner as stated above.

Results and Discussion

I. Hecate Strait Growth Curve

The relationship of length to estimated age of female dogfish in Hecate Strait is shown in Fig. 4A with a growth curve described by the familiar von Bertalanffy growth equation

$$l_t = L_\infty\ [1 - e^{-K(t-t_0)}]$$

where L_∞ is the theoretical average maximum length, K is the growth constant indicating the rate at which length approaches L_∞, l_t is the

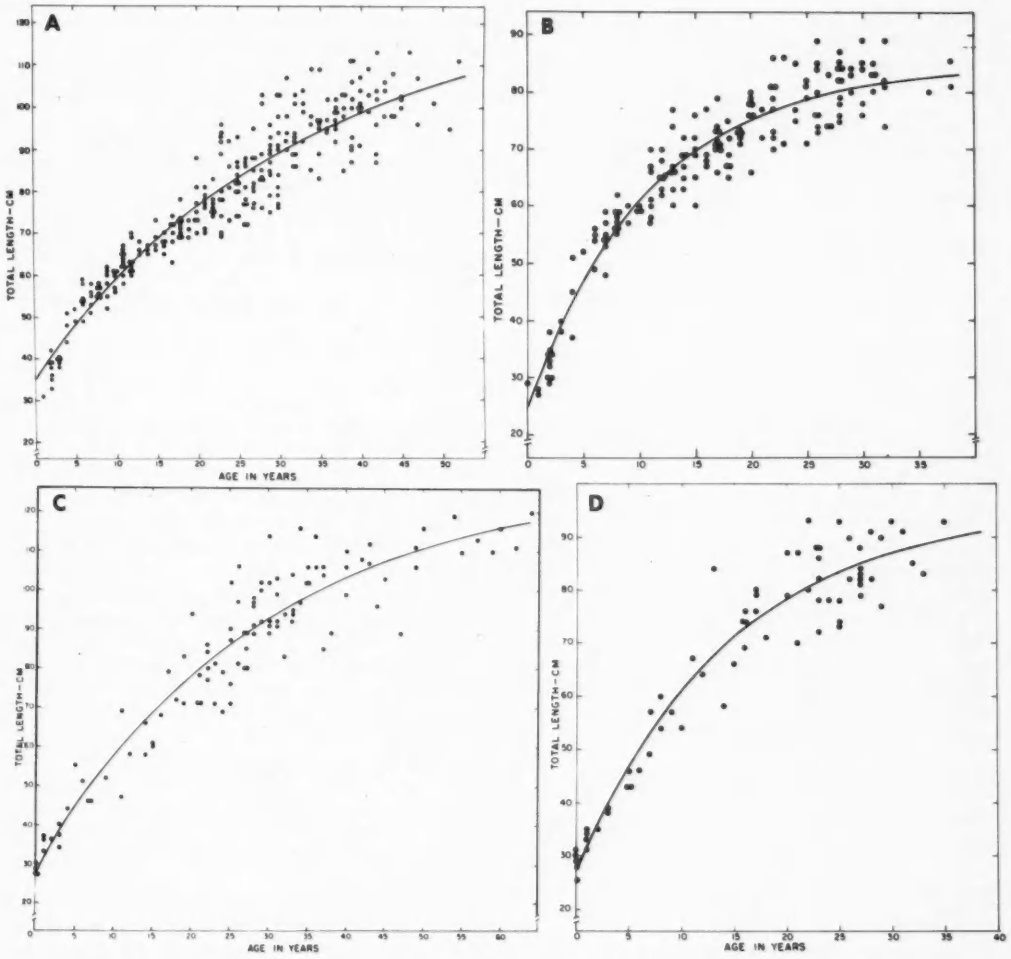

FIG. 4. Age–length relationship for A, female dogfish and B, male dogfish from Hecate Strait; C, female dogfish and D, male dogfish from the Strait of Georgia.

length at any given time t, and t_0 is the calculated time at which l is equal to zero.[2] The parameters of this curve are given in Table 1. To be well representative of growth in the early years, this curve should pass through age 0 at 26–27 cm, or the approximate length at birth (Ketchen 1972). The fit for the earliest ages is therefore poor.

Results for male dogfish are presented in the same form in Fig. 4B and Table 1. In contrast with the data on females, the growth curve seems to provide a better fit insofar as the early ages are concerned. It should be noted, however, that the part of the curve representing the oldest fish is probably biased downwards, because the Hecate Strait samples, for reasons unknown, contained no males greater than 89 cm in length, when in

[2]The computer program of Allen (1966), involving an iterative approach to fitting of von Bertalanffy growth curves, has been used here and elsewhere unless otherwise noted.

TABLE 1. von Bertalanffy growth parameters as estimated for the spiny dogfish, *Squalus acanthias*.

Area	Sex	K	L_∞ (*cm*)	t_0 (*yr*)
Hecate Strait	F	0.031	125.1	−10.6
	M	0.092	84.7	−3.7
Georgia Strait	F	0.034	129.1	−7.3
	M	0.067	96.1	−5.0
Washington coast	F	0.036	152.9	−6.7
	M	0.071	101.8	−5.2
North Sea[a]	F	0.11	101.4	−3.6
	M	0.21	79.7	−2.0

[a]From Holden and Meadows 1962.

fact lengths up to 100 cm are to be expected in representative samples from unfished populations (cf. data for Strait of Georgia males, Fig. 7; Barraclough 1948).

The apparently slower growth of male dogfish is supported by the difference in amount of wear on the spines, the NWP diameter tending to be broader among males than females for fish of about the same size. If the amount of abrasion is a function of age, as seems reasonable, then males of a given size must be somewhat older than females of the same size. The only other explanation is the possibility of a behavioral difference between the sexes as might occur, say, during courting or copulation.

II. Strait Of Georgia Growth Curve

Growth curves for female and male dogfish from the Strait of Georgia are presented in Fig. 4C and D, respectively, and the corresponding von Bertalanffy growth parameters appear in Table 2.

III. Estimated Age at Maturity

Figures 5A and B compare the growth curves of Hecate Strait and Strait of Georgia females and males, respectively, with the curves calculated from data used by Bonham et al. (1949)[3] and with those computed by Holden and Meadows (1962). For both sexes the Hecate Strait and Strait of Georgia curves show a substantially slower rate of growth. As a way of emphasizing the differences among these several calculated growth curves it is instructive to compare the estimated ages at maturity.

In the North Sea the average length at which female dogfish reach maturity is 82 cm, and the age corresponding to this length is 11 yr; the corresponding length and age of males are 60 cm and 5 yr (cf. Hickling 1930; Holden and Meadows 1962).

In British Columbia and adjacent waters the average length at which females reach maturity is 93.5 cm and for males, 72 cm (Ketchen 1972). Applying this information to the growth curves computed from the data of Bonham et al. (1949), the corresponding average ages of females and males at maturity are 20 and 11 yr, respectively. Reference to the Hecate Strait age–length curve leads to the startling, if not preposterous, conclusion that the average female dogfish attains maturity at an age of 34 yr with the corresponding age of males being 17 yr. Estimates for the Strait of Georgia are 31 and 16 yr, respectively, close to those for Hecate Strait.

Kaganovskaia (1933), also using spines for age determination, observed no mature females less than 19 yr or 100 cm in sampling conducted in the northwestern Pacific (northwestern Sea of Japan). This minimum size corresponds to an age of 41 yr on the Hecate Strait curve, 36 yr on the Strait of Georgia curve, and 22 yr on the "Bonham" curve. The age difference merely emphasizes the fact that Kaganovskaia's data suggested an even more rapid growth rate than those of Bonham et al. (1949). Indeed, as noted by Holden and Meadows (1962), over the range of sizes and ages recorded, Kaganovskaia's data show no sign of proceeding to an asymptote. Again, the fact that spines too worn or too difficult to read were rejected from the analysis could well have led to a substantial overestimation of growth rate.

North Sea observations aside, regardless of which growth curve is used it must be concluded that (granted age estimation is not grossly in error) the onset of maturity occurs at an advanced age among Pacific dogfish.

As the conclusions of Holden and Meadows (1962) are not held in dispute here, attention will henceforth be restricted to consideration of the substantial difference between the results of Bonham et al. (1949) and those obtained for Hecate Strait and the Strait of Georgia. While the dogfish of the North Sea (and the northwestern Atlantic) is apparently morphologically indistinguishable from that of the North Pacific, it possesses attributes that suggest a metabolic or physiological difference. It appears to have a much more rapid initial growth rate, reaches maturity at a much smaller size, does not grow to as large a size, and in all probability has a

[3]The basic data were not contained in this publication, but have since been kindly provided by Kelshaw Bonham through personal communication.

TABLE 2. Observed growth increments of tagged female dogfish as compared with increments predicted from Hecate Strait, Strait of Georgia, and "Bonham" growth.

Set	Specimen no.	Tagging agency	Length at tagging (*cm*)	Length at recap. (*cm*)	Years at large	Observed increment (*cm*)	Predicted increment: Hecate Strait (*cm*)	Predicted increment: Georgia Strait (*cm*)	Predicted increment: Bonham (*cm*)
A	1	FRB	70.0	76.0	2.17	6.0			
	2	WSFD	73.0	76.5	2.44	3.5			
	3	"	55.5	62.5	2.88	7.0			
	4	"	53.0	71.5	3.88	18.5			
	5	FRB	65.0	84.0	5.50	19.0			
	6	"	65.0	79.0	7.92	14.0			
	7	WSFD[a]	63.5	77.5	8.58	14.0			
Avg			63.5	75.3	4.47	11.7	8.1	9.6	13.6
B	1	WSFD	50.5	52.5	0.84	2.0			
	2	"	50.5	56.5	0.93	6.0			
	3	"	57.0	58.5	0.94	1.5			
	4	"	54.5	55.0	0.94	0.5			
	5	"	57.5	58.5	0.98	1.0			
	6	"	49.5	51.5	0.99	2.0			
	7	"	51.0	52.5	0.99	1.5			
Avg			52.9	55.0	0.94	2.1	2.1	2.4	3.4

[a]From Kauffman (1955). All other data from Washington State Fisheries Department (WSFD) kindly provided through personal communication (Holland 1972).

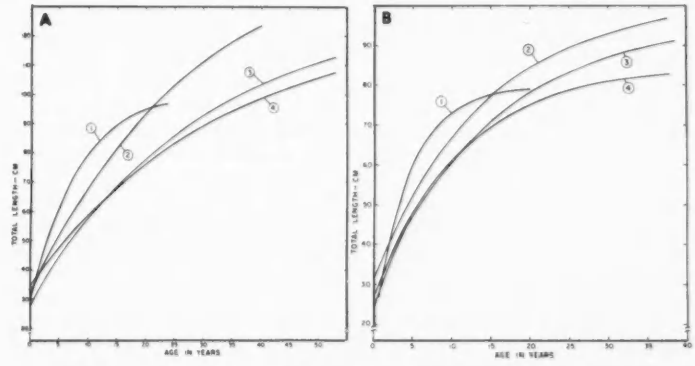

FIG. 5. Comparison of von Bertalanffy growth curves for A, female dogfish and B, male dogfish from 1. North Sea (Holden and Meadows 1962); 2. Washington (Bonham et al. 1949); 3. Strait of Georgia; 4. Hecate Strait.

shorter natural life span than its relative in the North Pacific. However, until more information is at hand, the importance of environmental differences cannot be discounted.

IV. CORROBORATING EVIDENCE

From this point onward comparisons will be restricted to female dogfish from the Strait of Georgia and data on the same sex from Bonham et al. (1949) and other sources, applying to adjacent coastal water of the state of Washington.

(1) Tag Returns — Although many thousands of dogfish were tagged during the 1940s, very few of the recoveries had been at large for more than a year and few were returned with reliable measurements of length at time of recapture.

Table 3 provides information on 14 female dogfish measured by biologists at time of recap-

TABLE 3. Comparison of peaks in length-frequency distribution of female dogfish sampled in December 1969–February 1970 with those among fish sampled approximately 2 yr later (November 1971) on the same fishing ground in the Strait of Georgia (measurements in centimeters).

Peak key	Length at peak		Assumed increment	Calculated increment	
				Georgia Strait	Bonham
AA_1	74	78	4	3.7	5.4
BB_1	76	80	4	3.5	5.1
CC_1	79	83	4	3.2	5.0
DD_1	82	85	3	3.1	4.8
EE_1	85	88	3	2.9	4.7
FF_1	87	90	3	2.7	4.5
GG_1	(91.5)	(94.5)	3	2.5	4.2

ture as well as at time of tagging. The data have been separated into two sets: A) recaptures which were made no less than 1.7 yr (20 mo) after tagging, and B) recaptures made 10–12 mo after tagging. The observed increments of growth in Set A over an average of 4.47 yr averaged about 11.7 cm, an amount about 4.4 and 2.1 cm more than that predicted by the Hecate Strait and Strait of Georgia growth curves, respectively, but 4.8 cm less than that predicted by the "Bonham" curve. Thus, the Strait of Georgia curve provides a fractionally better fit to the tagging data than the other two curves.

In Set B, dealing with the growth of relatively small fish at large for 10–12 mo, the observed average increment (2.1 cm over an average of 0.94 yr or 343 days) was, for practical purposes, about the same as that predicted by the Hecate Strait and Georgia Strait curves, but 1.3 cm less than that predicted by the "Bonham" curve.

Regardless of this evidence that growth calculated from tag returns is slightly more in accord with the Strait of Georgia and Hecate Strait curves, it is important to note that Bonham et al. (1949) observed substantial numbers of presumably accurately measured tagged fish which were shorter after recapture than they were at time of tagging. Holland (1957), reviewing results to that date reported that, of 23 dogfish at large for a year or more and measured by biologists upon recapture, seven had decreased in length. In more recent studies (1969–71) conducted by the Washington State Department of Fisheries, G. DiDonato (personal communication) reports that, of 89 recaptured tagged fish measured by government agency representatives, 25 had been at large for at least 1 yr and of these, six showed no growth and nine showed a decrease in length.

If the tag or the tagging process not only has an initial detrimental effect on growth but also in some way impedes growth over a protracted period, then growth rate as indicated by tagging is likely to be underestimated. The fact that tag returns reveal a high incidence of zero or negative growth is in itself an indication that the growth of dogfish is slow. However, this must be tempered by the fact that the dogfish has a cartilaginous skeleton that probably is subject to shrinkage after death sufficient to cancel out whatever growth may have occurred during the period at large. In any case, little confidence can be placed in tag returns to provide anything more than a minimum estimate of growth rate. What evidence there is suggests that the Strait of Georgia curve is closer to that minimum than the "Bonham" curve.

(2) Modes in length-frequency distributions — Bonham et al. (1949) were able to detect a pattern of modes in the length-frequency distribution of small dogfish within the range of 44–70 cm (average about 61 cm) and concluded that the annual average increment of growth was 3.3 cm, in close accord with their calculation of 3.1 cm based on age readings from spines. These data contrast with 2.0 and 2.4 cm as calculated for Hecate Strait and Strait of Georgia dogfish, respectively.

Although dogfish have been heavily sampled in Canadian waters, no parallel examination has been possible because of the scarcity of specimens in the 44–70-cm size range. However, some clues appear to be offered by a comparison of large samples of medium-sized female dogfish collected in the winter of 1969–70 in the "Gulf Islands" area of the Strait of Georgia with those collected

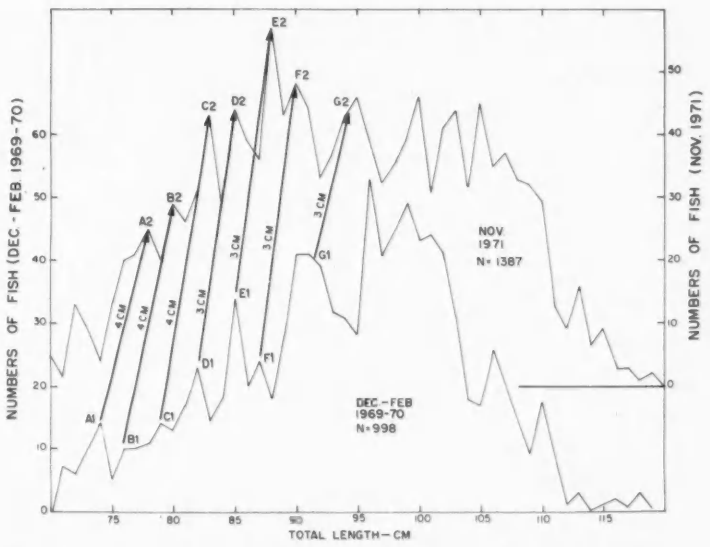

FIG. 6. Matching of length-frequency distributions of female dogfish sampled 2 yr apart on fishing grounds among the "Gulf Islands" in the southwestern part of the Strait of Georgia.

almost 2 yr later (November 1971) from the same locality. On the ascending limbs of the length-frequency distributions for the two periods there appears to be an orderly correspondence among at least six peaks (A_1A_2 through F_1F_2 in Fig. 6). Peaks occurring between 74 and 79 cm in the 1969–70 sample are matched by a 4-cm shift to the right in the 1971 sample. Likewise three peaks between 82 and 87 cm are matched by a 3-cm shift in the later sample. Beyond 90 cm, however, the order breaks down. A 3-cm shift can be obtained only in respect to line G_1G_2 by estimating the average lengths in the two domes (between 86 and 95 cm vs. 92 and 97 cm in the later sample). For peaks between 96 and 101 cm (1969–70 data) the matching is accomplished by 4 cm shifts, inconsistent with the trend exhibited by fish in smaller size intervals.

Table 3 compares these assumed 2-yr growth increments with those calculated from the Strait of Georgia growth equation for female dogfish. Allowing for rounding of the assumed increments, they are in close agreement with the calculated increments based on the Strait of Georgia growth curve. In contrast, the calculated increments from the "Bonham" growth equation average about 1.5 cm greater than the increments assumed from the shift of peaks in length-frequency data. Thus the evidence, though possibly fortuitous, is more in favor of the Strait of Georgia growth curve.

Little is known about the growth of dogfish in the first few years after birth. Small fish, less than 45 cm, are generally absent from catches with small-mesh bottom trawls. However, in the course of experimental work on midwater trawls in and around the Strait of Georgia in the winter months, small numbers of young dogfish were encountered from time to time. Their aggregate length-frequency distribution (Fig. 7) suggests three or possibly four modes. The first obviously represents fish of age 0 because the size at birth is between 26 and 27 cm. The second and third are at 31 and 37 cm, respectively, while a fourth questionable mode occurs at 40.5 cm. No useful purpose is served by trying to compare these observations with the average lengths calculated from the growth equations. The latter lengths must be regarded as unreliable since the growth curves do not pass through the known average length at birth.

(3) Female reproductive stages — Female dogfish have a gestation period of just under 2 yr (about 22 mo) and, as a rule, the young are born in the late fall. By early fall all but a small

TABLE 4. Average number of large ovarian eggs and term pups contained in female dogfish sampled in the autumn months of 1971, 1972, and 1973 in the "Gulf Islands" area of the Strait of Georgia.

		Parent length (*cm*)							
		80–84	85–89	90–94	95–99	100–104	105–109	110–114	115–119
Large ovarian eggs									
	n	1	28	82	134	167	128	59	14
	$\bar{x}$	3.00	4.93	5.20	6.27	6.99	8.02	8.76	8.86
Term pups									
	n	1	14	36	62	100	66	37	7
	$\bar{x}$	4.00	4.50	4.58	5.58	6.53	7.44	7.95	10.43

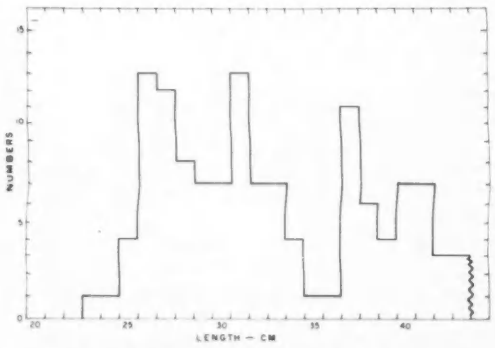

FIG. 7. Length-frequency distribution of small dogfish captured with midwater trawls in and around the Strait of Georgia (winters of 1964–65 to 1970–71).

fraction of the mature females can be assigned to one of three categories:

(i) those with large ovarian eggs (3–4 cm diam) nearing the stage for entry into a previously unoccupied uterus. These are virgin females reaching breeding condition for the first time;

(ii) those carrying both large ovarian eggs and uterine pups which are about to be liberated;

(iii) those with uteri containing 1-yr-old embryos and ovaries containing immature ova of 1.5–2.5 cm diam that will reach maturity in the succeeding year. Two techniques for using this information to obtain estimates of the growth rate of mature female dogfish will be examined with attention focused on females in the second of the foregoing categories — fish containing both large ovarian eggs and near-term pups.

(a) Bonham Method

A procedure developed by Bonham et al. (1949) invokes the basic assumptions that 1) the number of eggs and embryos increases with age and length of the parent, and 2) pregnant females of a given length (say, in early autumn) contain a constant average number of large ovarian eggs and term pups. Using a hypothetical example, suppose females of 100 cm are observed to contain an average of eight term pups and 10 large ovarian eggs, while females of $100 + x$ cm from the same year's sample are observed to contain 10 term pups. It would appear then that the growth increment is x cm with $x/2$ cm being the annual increment.

Data on pregnant females in category (ii), sampled in the Strait of Georgia in the autumn months of 1971, 1972, and 1973, have been combined in Table 4 to provide averages of the observed numbers of large ovarian eggs and term pups by 5-cm parent length intervals. Averages for the best represented length intervals are plotted in Fig. 8 and fitted by least squares. The horizontal distance between the two lines of best fit is about 3.3 cm, which would be the increment of growth for a 2-yr period, whence the annual increment is 1.6 cm.

Bonham et al. (1949), using the same technique, obtained an average annual increment of 3.5 cm, or more than twice that obtained above. The reason for this is that the method produces spurious results, as the so-called annual increment of growth is dependent on the relationship between the observed increase in number of eggs over embryos, by size of parent, and the true annual increment of growth. This can be demonstrated by a simple model taking a hypothetical case where the first condition is that the absolute average number of large ovarian eggs per female is anywhere from one to three more than the observed number of term pups being carried at the same time. (In nature, a female dogfish in the category under consideration carries an average of 0.58 more ovarian eggs than pups.) The second condition is that the rate of increase in numbers of eggs is 1.0 for every 5-cm increase in length of parent. (This rate is approximately the same

TABLE 5. Hypothetical model showing calculated growth increments of pregnant dogfish and their relation to actual increments and the average number by which large ovarian eggs exceed term pups in individual fish.

Increase in number of eggs over pups	Actual growth increment (*cm*)							
	1	2	3	4	5	6	7	8
1	+4	+3	+2	+1	0	−1	−2	−3
2	+9	+8	+7	+6	+5	+4	+3	+2
3	+14	+13	+12	+11	+10	+9	+8	+7

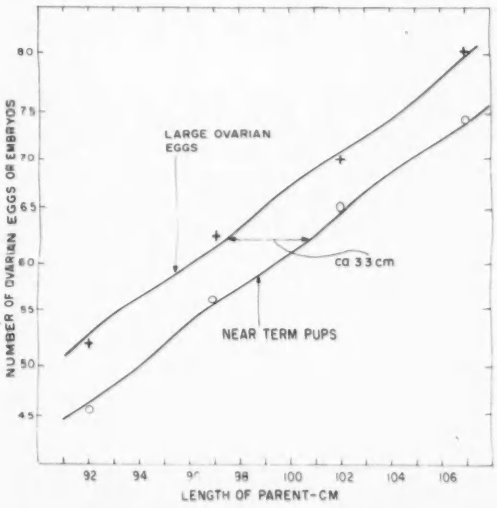

FIG. 8. Relationship between the numbers of large ovarian eggs carried by females of various sizes and the numbers of near-term pups carried by the same series of females at the same time (combined data for the October–November periods of 1971–73 — Strait of Georgia, "Gulf Islands" area).

as that observed in nature, cf. Ketchen 1972, figure 2.)

From the results in Table 5, it is clear that a wide range of calculated growth increments of the type obtained by the graphic approach (Fig. 8) can be expected in view of the dependence of the actual growth increment on the number by which the ovarian eggs exceed term pups. Indeed, within the 24 combinations examined, there was only one case in which the calculated increment agreed with the actual increment.

Further complications arise from the "Bonham" technique because the assumption that the number of eggs and embryos increases with age and length of the parent cannot be fully satisfied. While there is a correlation between egg, embryo, or pup number and length of parent, only 32% of the variability can be attributed to size of parent (Ketchen 1972). This is reaffirmed by the fact that, of 271 females (in the stage under consideration) examined in 1971–73, only 53% revealed a positive change in the number of large ovarian eggs over the number of term pups (27% actually contained one to four fewer eggs than pups). Thus the "Bonham" technique, though possessing *prima facie* evidence of validity, must be rejected.

(b) Year-Class Method

There is an alternative technique for estimating annual growth which is more direct and at the same time avoids assumptions about the relationship of egg or pup number to length of parent. When sampling is conducted in a given area and given time of year (say, the autumn months) for several years, it is to be expected that the difference between the average length of females carrying a specified number of large ovarian eggs in year x and the average length of females carrying the same number of first-year embryos in year $x + 1$ will be equal to the annual increment of growth. Likewise, the difference between the average length of females carrying a specified number of first-year embryos in year $x + 1$ and the average length of females carrying near-term pups in year $x + 2$ should also provide some indication of the annual increment of growth. This approach, of course, embodies the assumption that the dogfish sampled in a particular area and time of year each year are drawn from the same population. Results of tagging are too weak to support or refute this assumption in respect to waters in the "Gulf Islands" area in the southern Strait of Georgia. However, available information shows that there is at least some movement of dogfish in and out of the study area.

Average lengths of females carrying specified numbers of large ovarian eggs in the autumn of 1971 and 1972 are compared in Table 6 with

TABLE 6. Average lengths (centimeters) of female dogfish by egg or embryo number while bearing large ovarian or uterine eggs as compared with those in the succeeding year bearing first-year embryos.

Reproductive stage		No. eggs or embryos per female											
		3	4	5	6	7	8	9	10	11	12	Unweighted avg 5–8	Weighted avg all data[a]
Large ovarian eggs	1971												
	n	8	27	36	42	41	31	21	11	4	4		236
	$\bar{x}$	96.0	94.7	97.4	99.1	101.8	104.8	107.7	109.6	110.5	108.5	100.8	101.0
	1972												
	n	5	15	41	55	42	53	29	18	10	1		290
	$\bar{x}$	91.6	95.7	95.5	97.3	101.2	103.4	105.7	108.4	109.0	113.0	99.4	100.9
	1971–72 Weighted avg	94.3	95.1	96.4	98.1	101.5	103.9	106.5	108.9	109.4	109.4	100.0	100.9
First-year embryos	1972												
	n	9	26	41	71	71	53	32	18	8	4		368
	$\bar{x}$	99.0	94.6	96.5	100.0	101.8	103.8	104.4	107.8	110.0	108.8	100.5	101.4
	1973												
	n	2	3	13	17	28	17	21	10	6	5		189
	$\bar{x}$	93.5	98.7	100.8	99.9	103.5	105.7	106.6	108.6	109.2	112.2	102.5	103.6
	1972–73 Weighted avg	98.0	95.0	97.5	100.0	102.3	104.3	105.3	108.1	109.6	110.7	101.0	102.1
	Avg increment	+3.7	–0.1	+1.1	+1.9	+0.8	+0.4	–1.2	–0.8	+0.2	+1.3	+1.0	+1.2

[a]Includes additional data on fish with number of eggs or embryos less than three, greater than 12, and those fish for which the maturity stage was known but embryo count was incomplete (abortions) or not recorded.

TABLE 7. Average lengths (centimeters) of female dogfish by embryo or pup number while bearing first-year embryos as compared with those in the succeeding year bearing term pups.

Reproductive stage		No. embryos or pups											
		3	4	5	6	7	8	9	10	11	12	Unweighted avg 5–8	Weighted avg all data[a]
First-year embryos	1971												
	n	4	38	51	71	56	62	32	18	16	5		414
	$\bar{x}$	99.0	95.2	100.0	101.4	103.2	105.2	107.5	108.3	109.3	110.2	102.5	102.8
	1972												
	n	9	26	41	71	71	53	32	18	8	4		368
	$\bar{x}$	99.0	94.6	96.5	100.0	101.8	103.8	104.4	107.8	110.0	108.8	100.5	101.4
	1971–72 Weighted avg	99.0	95.0	98.4	100.7	102.4	104.6	106.0	108.1	109.5	109.6	101.5	102.1
Term pups	1972												
	n	12	18	36	32	31	17	6	8	8	1		183
	$\bar{x}$	99.1	96.3	97.8	100.7	101.3	104.6	108.2	109.5	110.0	107.0	101.1	101.6
	1973												
	n	4	9	13	24	21	24	15	8	3	–		136
	$\bar{x}$	94.0	97.7	100.9	100.3	103.6	105.8	105.9	107.4	109.0	–	102.7	103.2
	1972–73 Weighted avg	97.9	96.8	98.6	100.5	102.2	105.3	106.6	108.5	109.7	–	101.7	102.3
	Avg increment	–1.1	+1.8	+0.2	–0.2	–0.2	+0.7	+0.6	+0.4	+0.2	–	+0.2	+0.2

[a]Includes additional data on fish with number of embryos or pups less than three, greater than 12, and those fish for which the maturity stage was known but embryo count was incomplete (abortions) or not recorded.

TABLE 8. Observed increments of growth between females carrying large ovarian eggs and those carrying first-year embryos compared with increments calculated by the Strait of Georgia and "Bonham" growth equations (measurements in centimeters).

No. ovarian eggs or first-year embryos	Avg length of parent		Apparent annual increment	Predicted values			
				Strait of Georgia		"Bonham"	
	With ova	With embryos		Avg length	Increment	Avg length	Increment
5	96.4	97.5	1.1	97.5	1.1	98.4	2.0
6	98.1	100.0	1.9	99.1	1.0	100.0	1.9
7	101.5	102.3	0.8	102.4	0.9	103.3	1.8
8	103.9	104.3	0.4	104.7	0.8	105.6	1.7
Avg	100.0	101.0	1.0	101.0	1.0	100.0	1.9

those carrying the same numbers of first-year embryos in 1972 and 1973. Parallel comparisons of females carrying first-year embryos and term pups are shown in Table 7. Data for each pair of years have been averaged to reduce the variability in calculated growth increments, but this still persists as evidenced by negative values, particularly in the supposedly well-sampled embryo–pup categories in Table 7. The trouble arises in part from the fact that, with few exceptions, the average lengths of females in the various categories taken in 1972 were less than those in comparable categories in 1971 and 1973. Aside from the year to year differences in dates of sampling within the October–November period, no explanation can be offered for the 1972 anomaly. The fishing locality, trawling gear, persons conducting the sampling, conditions and techniques of sampling were essentially the same in all 3 yr. It is presumed therefore that the problem lies in unrepresentative sampling or unsoundness in the assumption of discreteness of the population in the study area.

Since the best-sampled egg–embryo categories of Table 6 yielded positive growth increments, that table is obviously more instructive than Table 7. The increments for the categories of five to eight eggs or embryos shown in the last row of the former table are compared in column 4 of Table 8 with values predicted from the Strait of Georgia (column 6) and "Bonham" (column 8) growth equations for females. The observed increments of growth, averaging 1.0 cm/annum, are in closer accord with those from the Strait of Georgia equation (1.0 cm/annum) than with the values calculated from the "Bonham" equation (1.9 cm). It should be noted, however, that had unweighted averages been taken of the 1971–72 and 1972–73 observations in Table 6, the increments for the five to eight egg–embryo categories would have been 2.2, 1.8, 1.1, and 0.7 cm, respectively. Their average is 1.4 cm—a figure only marginally closer to the predicted Strait of Georgia increment than to the "Bonham" increment. Thus the conclusion is a tenuous one: within the size range of 95–105 cm, growth of females appears slightly better described by the equation calculated from the Strait of Georgia age determinations.

(4) Mercury accumulation as an age indicator — In recent years a great deal of attention has been given to the accumulation of mercury and other heavy metals in fish. Levels of total mercury as high as 1.96 ppm have been recorded from large dogfish captured in the Strait of Georgia (Forrester et al. 1972). If we were to assume that the average annual net uptake per fish is constant, then it should be possible to estimate the age of a dogfish, given some measure of the net uptake.

First-year embryos from 10 Strait of Georgia dogfish had an average mercury load of 0.027 ppm and second-year (near-term) pups from nine fish averaged 0.026 ppm. Childs et al. (1972) noted for dogfish from Oregon waters an average of 0.019 ppm for first-year embryos from seven fish and 0.037 ppm for second-year pups from two fish. The weighted average of all these observations is 0.026 ppm.

Childs et al. (1972) concluded that embryos and pups of dogfish are not exposed to the high concentrations of mercury found in maternal musculature. Thus one may presume that whatever the level of mercury in the embryos and pups, it was imparted by the parent prior to the descent of the ova into the uterus. While Childs et al. recorded an average level of 0.034 ppm in Graafian follicles of six females, it is presumed for present purposes that 0.026 ppm is the average amount of mercury transmitted to an ovarian egg during its final year of rapid development and

that no further exposure to mercury takes place until birth.

Forrester et al. (1972) calculated the relationship of mercury load to size of female dogfish in the Strait of Georgia:

$$Y = (186 \times 10^{-7})\ X^{2.347}$$

where Y is the total amount of mercury (ppm wet weight) and X is the length of fish in centimeters.

Recalling that the average female dogfish reaches maturity at a length of 93.5 cm, substitution of this length in the foregoing equation yields a value of Y = 0.79 ppm of mercury. If, as has been suggested in Section III(3) above, the corresponding average age at maturity is 31 yr, then net mercury accumulation at 0.026 ppm/year should amount to 31 × 0.026 or 0.81 ppm — practically the same figure as the above. However, using the growth curve developed from the data of Bonham et al. (1949), the average age at maturity is 20 yr, whence the mercury content is estimated as 20 × 0.026 or 0.52 ppm — substantially less than the predicted value of 0.79 ppm.

A more appropriate approach would be to go directly to the relationship between mercury load and estimated age, but this proves to be rather uninformative. From the curve in Fig. 9,[4] it can be seen that a load of 0.79 ppm of mercury corresponds with an age of about 32 yr — the same as that obtained with the assumption of a constant average annual net uptake of mercury. However, the confidence limits of such a curve are obviously so broad that even the "Bonham" estimate of 0.52 ppm of mercury at 20 yr of age could not be considered significantly anomalous. Thus, use of information on mercury load to corroborate age estimates is of doubtful value and it is necessary to regard as fortuitous the close agreement between the Strait of Georgia age estimates and those estimated from mercury load.

In the foregoing presentation of estimates of age and growth of dogfish in British Columbia waters, attention has been focused on the acceptability of a growth curve based on ages estimated from presumed annuli on the second dorsal spines. With respect to females, the calculated rate of growth is considerably slower than that estimated from data presented by Bonham et al. (1949) dealing with the same general area several decades earlier. The difference is illustrated by the disparity in the estimated ages at maturity — 31 and 20 yr, respectively.

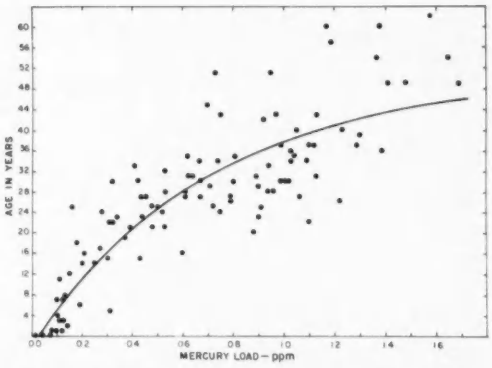

FIG. 9. Relationship of estimated age of female dogfish to total mercury load (Strait of Georgia, May–June, 1971).

The bits and pieces of information which have been enlisted to test the reliability of the two growth curves may be summarized as follows:

1, Bonham et al. concluded from observation of modes in length-frequency distributions for fish in the size range of 44–70 cm (average 61 cm) that the annual increment of growth was 3.3 cm. No comparable length-frequency data were available from the Strait of Georgia, but the age–length data for that area suggested that the annual increment for the size range in question was only 2.3 cm;

2, Modes in the length-frequency distribution of Strait of Georgia females of medium size suggested an annual increment of 2 cm between 74 and 79 cm and 1.5 cm between 82 and 87 cm. These increments were in closer accord with the Strait of Georgia growth curve than with those calculated from the date of Bonham et al. (1949);

3, Limited samples obtained with small-mesh midwater trawls in winter showed length modes at 26–27, 31, and 37 cm. Working from the observation that the average length at birth is 26.2 cm (Ketchen 1972), the second and third modes may represent lengths at the completion of the first and second year at large, with annual increments of 4.8 and 6.0 cm, respectively;

4, A comparison of the average lengths of

[4]The relationship is described by the function

$$Y = A\,[e^{-B(X-X_0)} - 1.0]$$

where Y is age in years, X is the mercury load in ppm, X_0 = 0.026 ppm, the calculated mercury load at birth, while A = –50.630 and B = 1.404. The latter two parameters were solved by using Hartley's (1961) modified Gauss-Newton method of least squares.

TABLE 9. Calculated length by age for male and female dogfish in the Strait of Georgia.

Age (yr)	Length (cm)		Age (yr)	Length (cm)		Age (yr)	Length (cm)		Age (yr)	Length (cm)	
	Male	Female		Male	Female		Male	Female		Male	Female
0	27.6	26.3	12	68.2	69.9	24	86.0	94.3	40	95.2	110.9
1	32.4	31.0	13	70.4	72.5	25	86.9	95.7	45	96.6	114.0
2	36.9	35.4	14	72.3	74.9	26	87.8	97.1	50	97.5	116.4
3	41.1	39.7	15	74.1	77.4	27	88.6	98.4	55	95.2	118.3
4	45.0	43.7	16	75.9	79.6	28	89.3	99.7	60	98.7	119.8
5	48.7	47.6	17	77.5	81.8	29	90.0	100.9	65	99.0	121.0
6	52.1	51.2	18	78.9	83.8	30	90.7	102.1	70	99.2	121.9
7	55.3	54.7	19	80.3	85.8	31	91.3	103.2	75	99.4	122.6
8	58.2	58.1	20	81.6	87.6	32	91.9	104.2	80	99.5	123.2
9	61.0	61.2	21	82.8	89.4	33	92.4	105.2	85	99.6	123.6
10	63.6	64.3	22	84.0	91.1	34	92.9	106.1	90	99.7	124.0
11	66.0	67.1	23	85.0	92.7	35	93.4	107.0	95	99.7	124.3

females carrying a given number of large ovarian eggs in 1 yr with those carrying the same number of first-year embryos in the succeeding year yielded results suggesting an average annual increment of 1.0 cm in the size range of 96–105 cm. This was precisely the same as that predicted from the Strait of Georgia curve as compared with an average of 1.9 cm predicted from the "Bonham" curve.

A von Bertalanffy growth curve for females which appears to best accommodate the "Bonham" observed increments in (1) above and the Strait of Georgia observed increments in (2), (3), and (4) has the following parameters: $K = 0.048$, $L_\infty = 125.3$ cm, and $t_0 = -4.88$ yr. Calculated lengths for age are provided in Table 9[5] along with estimates for male fish, derivation of which are considered below. The age corresponding to the average length at which females reach maturity (93.5 cm) is approximately 23 yr — considerably younger than the 31–34 yr estimated from the Strait of Georgia and Hecate Strait growth curves.

An age of 23 yr at maturity is, nevertheless, still surprisingly high. Yet, if true, it is not a completely unique feature among primitive fishes. Within the sturgeon family (Acipenseridae) in temperate North America, estimated ages at first spawning range from 26 to 34 yr for the white sturgeon (Semakula and Larkin 1968), 14 to 33 yr for the lake sturgeon (Harkness and Dymond 1961), and 27 to 28 yr for the Atlantic sturgeon (Scott and Crossman 1973). Of course, these species grow to a large size and evidence of their long-delayed maturation is therefore perhaps easier to accept. In any event, if the uniqueness of an observation is sufficient reason for it to be suspect, it should be remembered that the dogfish is factually unique in one other important respect. As far as is known to science, the phenomenon of a near-2-yr gestation period (22 mo or more), as observed in the dogfish, occurs nowhere else in the phylum Chordata, the closest rival being the elephant whose gestation period is variously estimated to be 18–21 mo.

To this point the growth rate of the male dogfish has received no discussion because of the lack of information to confirm or refute the age–length relationship as determined from spine readings. For this reason there is little recourse but to assume provisionally that the true growth rate lies midway between that estimated for the Strait of Georgia and that computed from the data of Bonham et al. 1949 (cf. Fig. 5B and Table 1). The compromise growth curve has parameters of $K = 0.0689$, $L_\infty = 99.8$ cm, and $t_0 = -4.70$ yr. Calculated lengths for age are provided in Table 9.

Conclusion

In view of the fact that none of the items of corroborating evidence, nor indeed the technique of ageing itself, is free from criticism, it is difficult to draw much more than a tentative conclusion. In essence the growth rate of the dogfish appears to be considerably slower than heretofore recorded, suggesting that females may take as long

[5]Alternatively a more objective approach involving the method of Fabens (1965) yields values of $K = 0.067$, $L_\infty = 111.0$ cm, and $t_0 = -4.03$ yr. However, the resulting curve provides a poorer fit. For this reason and the evidence that the theoretical average maximum length (L_∞) is substantially below the maximum length usually observed in unexploited stocks, these parameters have been rejected.

as 23 yr, on the average, to reach maturity. For males the comparable age is about 14 yr.

If this study has done nothing more than enunciate a hypothesis sufficiently controversial to stimulate further study by others, a useful purpose has been served. There is a large resource of dogfish along the coast of western North America. Its role in the ecosystem dynamics of the continental shelf must be of considerable significance, yet for want of attention it remains to this day largely a mystery.

For nearly 100 yr the dogfish has been loudly proclaimed as a major predator on young salmon (especially when returning runs of adults do not live up to expectations). Equally vociferous accusations have been made about its predation on herring — predation so heavy as to be a limiting factor on the abundance of herring available to the commercial fishery, and/or available as forage for other more valuable species. To date there is nothing substantive to support these claims, but neither is there much evidence to refute them. The only current view about which there can be no question is that the dogfish constitutes a serious nuisance, being responsible for gear damage and other losses in commercial fishing operations and in the recreational fishery for salmon. In any event, if the dogfish is to be subjected to an intelligent control program, or better, to broad-scale commercial utilization, much more information is required on its biology and life history. Its growth and replacement rates are but one facet of a very complex problem in urgent need of solution.

Acknowledgments

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Incorporation of Glycerol-3-Phosphate into the Hepatic Lipids of Rainbow Trout, *Salmo gairdneri*

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HOLUB, B. J., J. T. H. CONNOR, AND S. J. SLINGER. 1975. Incorporation of glycerol-3-phosphate into the hepatic lipids of rainbow trout, *Salmo gairdneri*. J. Fish. Res. Board Can. 32: 61–64.

The incorporation of *sn*-[^{14}C]glycerol-3-phosphate into the liver lipids of rainbow trout (*Salmo gairdneri*) was studied using a homogenate preparation. The reaction was dependent upon added palmitoyl-CoA as a source of activated fatty acid and lysophosphatidic acid as well as phosphatidic acid were found by means of thin-layer chromatography to be important metabolic products. The optimal conditions for studying glycerol-3-phosphate acyltransferase activity in the liver of rainbow trout are given. The maximum rate of entry of glycerol-3-phosphate into lipid esters was 91 μmoles/g liver per hour.

HOLUB, B. J., J. T. H. CONNOR, AND S. J. SLINGER. 1975. Incorporation of glycerol-3-phosphate into the hepatic lipids of rainbow trout, *Salmo gairdneri*. J. Fish. Res. Board Can. 32: 61–64.

Nous servant d'une préparation d'homogénat, nous avons étudié l'incorporation du *sn*-[^{14}C]glycérol-3-phosphate dans les lipides hépatiques de la truite arc-en-ciel (*Salmo gairdneri*). La réaction dépend de l'addition de palmitoyl-CoA comme source d'acide gras activé. Nous avons de plus trouvé, par chromatographie sur couche mince, que l'acide lysophosphatidique aussi bien que l'acide phosphatidique étaient d'importants produits métaboliques. Nous indiquons les conditions optimales d'étude de la glycérol-3-phosphate acyltransférase dans le foie de la truite arc-en-ciel. Le taux maximal d'entrée du glycérol-3-phosphate dans les esters de lipides est de 91 μmoles/g de foie par heure.

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IN view of the important role of fats as energy stores in fish, there have been several extensive studies dealing with lipolytic reactions in such tissues as fish muscle (Bilinski 1969; Bilinski et al. 1971). However, there is a paucity of information on the biosynthetic pathways leading to the formation of neutral and polar lipids in fish and other aquatic organisms (Tarr 1972). This is rather unfortunate in view of the important role of these lipids as energy reserves and essential components of biological membranes (Tashima and Cahill 1965; Stoeckenius and Engelman 1969). Although a number of compositional and isotopic studies on lipids in fish tissues have been conducted in vivo (Tarr 1972; Castell et al. 1972; Kluytmans and Zandee 1973; Robinson and Mead 1973; Malins and Robisch 1972), these reports do not provide information on the rates of lipid biogenesis. Because the acylation of *sn*-glycerol-3-P by activated fatty acids is known to be an important initial step in lipid formation in most mammalian systems (Daae 1973), we have established conditions for studying this process in livers of rainbow trout. The liver was chosen because of its central role in fatty acid esterification to higher glycerides and transport of lipid to extrahepatic tissues such as skeletal muscle.

Materials and methods — The coenzyme A thiol-ester derivative (palmitoyl-CoA) was obtained from Nutritional Biochemicals. The *sn*-[U-^{14}C]glycerol-3-phosphate was purchased from the New England Nuclear Corp. and diluted with *rac*-glycerol-3-phosphate (Sigma Chemical Co.) to obtain the desired specific activity (10,000 cpm/μmol *rac*-glycerol-3-phosphate). The standard lipids for thin-layer chromatography (TLC) included neutral lipids and phospholipids and were obtained from Serdary Research

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Laboratories. Silica gel (G and H) was purchased from Canlab. PPO (2, 5 diphenyloxazole) and POPOP [1,4-bis-2(4-methyl-5-phenyl-oxazolyl)benzene] were supplied by Amersham Searle. Crystalline bovine serum albumin (BSA) was obtained from the Sigma Chemical Co. All chemicals and solvents were of analytical grade.

Fish and preparation of liver homogenates — Rainbow trout weighing approximately 180 g were maintained in aquaria at 12–13 C and fed a well-balanced diet. Fish were sacrificed by a blow on the head and the livers were rapidly excised, rinsed in cold 0.25-M sucrose containing 50 mM Tris-HCl (pH 7.4), blotted, and weighed. The livers were immediately cut into small pieces and homogenized in 4 vol of the iced sucrose-Tris buffer using a Potter-Elvehjem homogenizer with a Teflon pestle. The crude homogenate was centrifuged at 800 × *g* for 10 min to remove cell debris. The supernatant (purified homogenate) was removed and immediately used as the enzyme source. The protein content of the purified homogenate was determined by the method of Lowry et al. (1951) using BSA as standard.

Assay procedures — The concentrations of adenine and thiol ester in the acyl-CoA preparations used were calculated from the absorbances at 260 and 232 nm, respectively, using a Unicam SP500 Spectrophotometer and the extinction coefficients given by Seubert (1960). The concentration of the thiol ester was confirmed by determining the amount of free CoA liberated from aliquots of the palmitoyl-CoA solutions by pancreatic lipase (Barber and Lands 1971). Unless stated otherwise, the standard assay for monitoring glycerol-3-phosphate incorporation into lipid was as follows. The assay mixture contained 50 mM Tris-HCl buffer (pH 7.4), 20 mM [^{14}C]glycerol-3-phosphate, 100 μl of the enzyme preparation (3.00 ± 0.15 mg of protein, mean ± SE), and 55 μM palmitoyl-CoA in a final volume of 1.5 ml. The reaction was initiated by the addition of enzyme and the incubation conducted in a metabolic shaker at 15 C for the times denoted. The reaction was quickly terminated by the addition of 2.25 ml of *n*-butanol with a Repipet dispenser followed by 3.0 ml of water, according to the procedure of Daae (1973). The mixture was shaken, centrifuged, and the butanol phase recovered using a Pasteur pipette and washed with 4.5 ml of water which had previously been saturated with butanol. The two phases were again separated using a clinical centrifuge and aliquots of the butanol phase were taken for determination of radioactivity or TLC.

For radioactivity measurements, aliquots of the total lipid extract were transferred to counting vials and the solvent evaporated under nitrogen. Radioactivity was measured in a Nuclear Chicago Mark I liquid scintillation counting system after adding 10 ml of a scintillation mixture (4 g PPO, 50 mg POPOP, and 200 ml Triton X-100 per liter of scintillation grade toluene). Quenching was monitored by the external standard channel ratios method. The reaction was measured as nmoles of *sn*-[^{14}C]glycerol-3-P incorporated into lipid.

Thin-layer chromatography of reaction products — The total lipid extracts were dissolved in chloroform–methanol (1:1, vol/vol) and chromatographed in appropriate TLC systems. The formation of monoglycerides, diglycerides, triglycerides, and phospholipids was determined in light petroleum–acetone–formic acid (76:24:0:2, by volume) on silica gel G and 0.5 M oxalate (Possmayer and Mudd 1971). Individual neutral lipids were separated in heptane–isopropyl ether–acetic acid (60:40:3, by volume) on silica gel G (Holub and Kuksis 1971) and phospholipids were separated in chloroform–methanol–acetic acid–water (25:15:4:2, by volume) on silica gel H (Skipski et al. 1964). The plates were activated at 115 C for at least 1 h before use and neutralized by brief exposure to ammonia vapor after development. Lipid bands were detected after either a brief exposure to iodine vapor or by examination under ultraviolet light after spraying with 2,7-dichlorofluorescein in methanol–water (50:50, by volume). The radioactive lipids were identified by comparison of their R_F values with authentic standard and co-chromatography in the various TLC systems. The designated bands were scraped directly into counting vials. Ten milliliters of scintillation fluid was added and radioactivity measured as described above.

Results — Conditions for sn-[^{14}C]-glycerol-3-P entry into lipid — The incorporation of glycerol-3-P into lipid as a function of time of incubation is given in Fig. 1. The reaction was linear for the first 3 min after which a plateau was maintained with incubation periods of 3–9 min. Thus, incubation periods of 3 min duration were used routinely

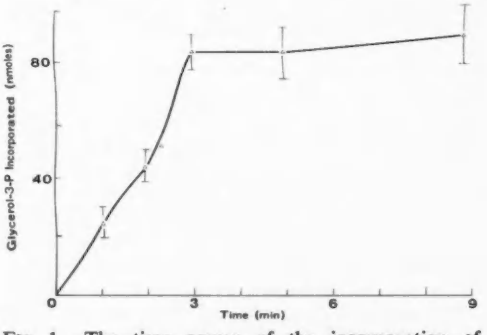

FIG. 1. The time course of the incorporation of [^{14}C]glycerol-3-phosphate into hepatic lipid of rainbow trout (*Salmo gairdneri*). Vertical bars represent SE of the mean from three to five experiments.

for most studies on factors controlling lipid synthesis from glycerophosphate.

The effect of enzyme concentration on the rate of lipid synthesis is shown in Fig. 2. A steady increase in the amount of product formed was observed with an increase of homogenate protein up to a concentration of 3.2 mg/1.5 ml of incubation medium. Doubling the protein concentration to 6.4 mg gave only an 8% increase in product. Therefore, protein levels of 3.0 ± 0.15 mg/1.5 ml (mean ± SE) were used in the standard assay conditions. The rate of reaction obtained when 3.0 mg of enzyme protein obtained from different fish livers ($n = 5$) were incubated under similar conditions was 90.7 ± 7.8 nmoles per incubation/3 min.

Figure 3 shows the effect of added palmitoyl-CoA on glycerophosphate entry into hepatic lipids. A linear relationship between reaction velocity and increasing palmitoyl-CoA levels was observed up to 55 μM acyl-CoA. A marked inhibition (54%) of lipid synthesis was observed at much higher palmitoyl-CoA concentrations (110 μM). The enhancement of the reaction by activated fatty acid is evidenced by the fact that glycerophosphate entry into lipid in the absence of palmitoyl-CoA was only 2–3% of that when it was present at optimal levels (Fig. 3).

The concentration of added *rac*-glycerol-3-phosphate used in the standard assay was 20 mM. This level was deemed optimal because a concentration of 13.3 mM did not alter the reaction rate,

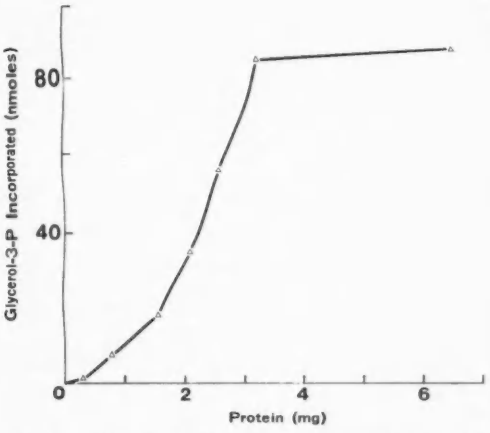

FIG. 2. The effect of enzyme concentration on the incorporation of [^{14}C]glycerol-3-phosphate into hepatic lipid of rainbow trout. The data are average values from two separate experiments.

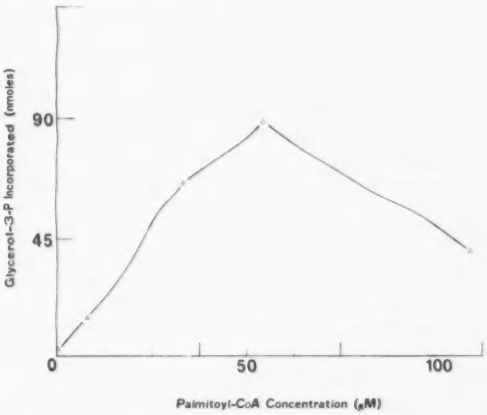

FIG. 3. The effect of palmitoyl-CoA concentration on the incorporation of [^{14}C]glycerol-3-phosphate into hepatic lipid of rainbow trout. The data are average values from two separate experiments.

and concentrations of 33.3 and 80 mM gave only 15 and 35% increases, respectively, in velocity.

Thin-layer chromatography of reaction products — The neutral lipids and phospholipids contained 23 and 77%, respectively, of the total radioactive lipids synthesized by the trout liver homogenates (Table 1). The lipids formed were 19% monoglycerides plus diglycerides while 17 and 54% were phosphatidic acid and lysophosphatidic acid, respectively.

Discussion — A number of compositional and isotopic studies have resulted in speculation that the biosynthesis of complex lipids in fish tissues may be via pathways similar to those in mammalian systems (Kennedy 1961). However, little direct evidence has been offered on the biochemi-

TABLE 1. Distribution of radioactivity among hepatic lipids of ranbow trout (*Salmo gairdneri*) following incubation with *sn*-[^{14}C] glycerol-3-phosphate.[a]

Lipid fraction	% of total radioactivity
Total neutral lipids	23
Monoglyceride plus diglyceride	19
Triglyceride plus unidentified lipid	4
Total phospholipids	77
Phosphatidic acid	17
Lysophosphatidic acid	54
Other phospholipids	6

[a]The data are average values from two separate experiments.

cal mechanism(s) involved. The present results provide evidence for the incorporation of labelled glycerol-3-phosphate into the neutral and polar lipid esters of rainbow trout liver. The dependency of this reaction on activated fatty acid, in the form of palmitoyl-CoA, and the isolation of radioactive lysophosphatidic acid and phosphatidic acid from the incubation medium provide direct support both for glycerol-3-phosphate acyltransferase activity in trout liver and for lipid synthesis via phosphatidic acid as recognized in mammalian systems (Kennedy 1961).

The maximum rate of glycerol-3-phosphate acyltransferase activity in the homogenate preparations from the livers of rainbow trout under optimal conditions was found to be 0.6 μmoles/mg protein per hour or 91 μmoles/g liver per hour. The physiological significance of this apparently high potential for lipid synthesis in the livers of rainbow trout awaits further investigation and comparison with other tissues. It is also known that a number of environmental factors can affect lipid levels in selected tissues of fish (Knipprath and Mead 1968; Stickney and Andrews 1971). The possible effect of such factors on glycerol-3-phosphate acyltransferase activity in these tissues as measured in vitro awaits further investigation.

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Concentrations of Circulating Progesterone During Early Pregnancy in the Northern Fur Seal, *Callorhinus ursinus*

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DANIEL, J. C. JR. 1975. Concentrations of circulating progesterone during early pregnancy in the northern fur seal, *Callorhinus ursinus*. J. Fish. Res. Board Can. 32: 65–66.

The concentration of circulating progesterone in the female of the northern fur seal (*Callorhinus ursinus*) was found to be low at and for about 3½ mo after ovulation, but began to increase prior to implantation and continued to rise for at least 1 mo thereafter.

DANIEL, J. C. JR. 1975. Concentrations of circulating progesterone during early pregnancy in the northern fur seal, *Callorhinus ursinus*. J. Fish. Res. Board Can. 32: 65–66.

L'auteur constate que la concentration de progestérone en circulation chez l'otarie à fourrure du nord (*Callorhinus ursinus*) est faible pendant l'oestrus et pendant environ 3½ mois après l'ovulation, mais qu'elle commence à augmenter avant l'implantation et continue de le faire pendant au moins 1 mois après.

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THIS is a report on concentrations of circulating progesterone in the northern fur seal (*Callorhinus ursinus*) during the first 5 mo of pregnancy.

Blood samples were collected from 28 adult female fur seals trapped on the Pribilof Islands, Alaska or pelagically. All samples were stored frozen and shipped in dry ice to my laboratory at the University of Tennessee where they were thawed and centrifuged and progesterone concentrations determined on the serum supernatant using the competitive protein binding technique of Johansson (1970).

The concentrations (Fig. 1) remained low during the period when implantation was delayed, not starting to increase until immediately before embryo reactivation. The initial rise in progesterone was coincidental with occurrence of an "estrogen surge" (Daniel 1974) and with increased uterine protein secretion and enlargement of the corpora lutea (Daniel 1971).

These data correlate well with two of the three periods of steroid domination defined by Craig (1964) from her histological studies of fur seal reproductive tracts, in that the second period is a refractory stage lasting about 2–2½ mo and the third, immediately prior to implantation, is luteal. Her first period of 1-mo duration following ovulation, and presumably also luteal, does not correlate with my findings of low circulatory progesterone levels. There may, however, be selective uptake by uterine target tissues that obviously would not be detectable in these studies.

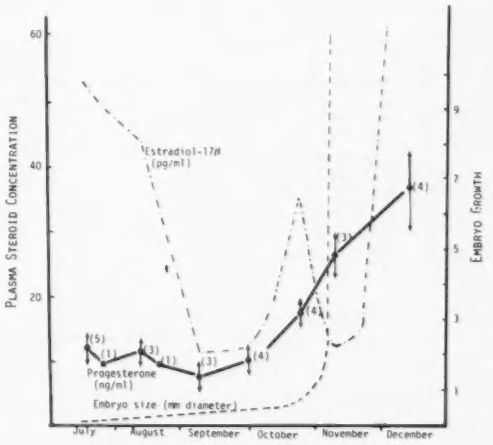

FIG. 1. Concentrations of progesterone for the northern fur seal (*Callorhinus ursinus*) from ovulation to 1½ mo after implantation in relation to those for estrogen (Daniel 1974) and to growth of the embryo (Daniel 1971). Numerals in parentheses are numbers of seals sampled.

This is the first report of circulating progesterone measurements made in pinnipeds of which I am aware, but progesterone concentrations in other species having delayed implantation show similar

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patterns: for example, in the spotted skunk, *Spilogale putorius* (Mead and Eik-Nes 1969), and in mink, *Mustela vision* (Duby et al. 1972 and Murphy 1973).

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Maturation and Spawning of Atlantic Herring (*Clupea harengus harengus*) in the Southern Gulf of St. Lawrence[1]

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MESSIEH, S. N. 1975. Maturation and spawning of Atlantic Herring (*Clupea harengus harengus*) in the southern Gulf of St. Lawrence. J. Fish. Res. Board Can. 32: 66–68.

Analysis of maturity stages of herring samples taken from the southern Gulf of St. Lawrence shows two maturation cycles for spring and autumn spawning herring. The spring population has a spawning peak in May and the summer–autumn population extends spawning from July through September. Spawning grounds of spring and autumn herring populations and their nursery areas are mapped.

MESSIEH, S. N. 1975. Maturation and spawning of Atlantic herring (*Clupea harengus harengus*) in the southern Gulf of St. Lawrence. J. Fish. Res. Board Can. 32: 66–68.

L'analyse des stades de maturité d'échantillons de harengs provenant du golfe Saint-Laurent méridional démontre l'existence de deux cycles de maturation chez les harengs qui fraient au printemps et en automne. La population de printemps a un pic de fraie en mai, et la population d'été–automne a une période de fraie qui s'étend de juillet à septembre inclusivement. Les auteurs indiquent sur cartes l'emplacement des frayères et des aires d'alevinage des populations de harengs de printemps et d'automne.

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PART of an intensive herring research program at the St. Andrews Station was directed towards delineating herring stocks in the southern Gulf of St. Lawrence, and studying their biological characteristics. This area supports a major fishery for spring and autumn herring, with fishing effort being mainly concentrated on the fish during their spawning and feeding migrations. For fishery management purposes, it is essential to know the spawning seasons, and to locate the spawning grounds of the fish, to implement the appropriate regulatory measures to protect the fishery.

[1]Most of the information in this report was included as a part of a thesis submitted to McGill University in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

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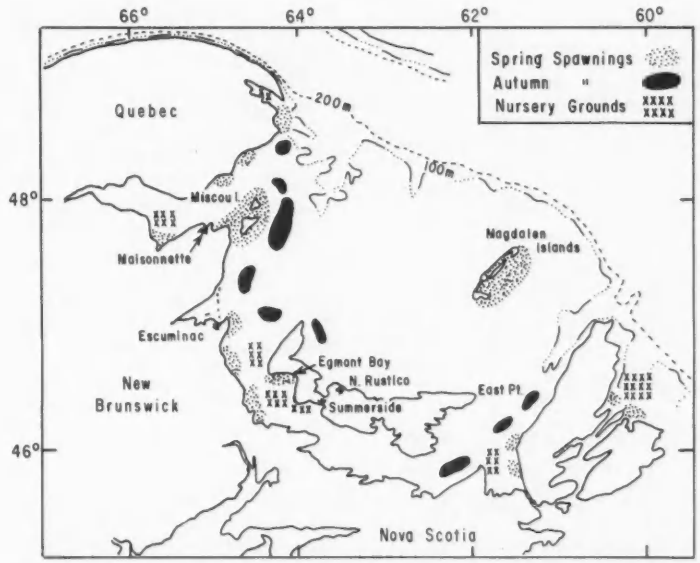

FIG. 1. Southern Gulf of St. Lawrence showing Atlantic herring (*Clupea harengus harengus*) spawning grounds and their nursery areas.

Materials and methods — Records of spawning localities and times were collected from the Fishery Officers, fishing vessel skippers, and from examination of the maturity of more than 13,000 herring collected from the commercial catches during 1965 through 1970. Maturation cycles of spring and autumn herring populations were studied from the 1970 samples, which included 2180 fish caught during April through December. Maturation stages of these samples were classified into eight stages as recommended by ICES (Anon. 1962).

Results — Mapping of herring spawning grounds on the Magdalen Shallows is shown in Fig. 1. The nursery areas as indicated by catches of juvenile and immature herring in the area are also shown. Except off the Magdalen Islands, where there is only spring spawning ground, most other localities support both spring and autumn spawning grounds. The relative strengths of the two spawning groups varied by locality. The autumn spawning grounds were generally spread more offshore. Although not shown in the Figure, there were records of small local stocks of spring spawning herring in practically every bay.

Different maturation stages of herring were expressed as percentages of the total in each sampling month (Fig. 2). There were no samples for the months January through March as there was no fishery during these months. Maturation stage "6" represents fish in ripe and running condition, and hence it is most indicative of spawning fish. It is clear that there are two maturation cycles, and two spawning seasons separated by a short period in June. The spring

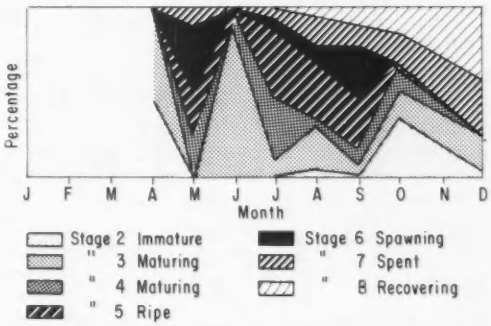

FIG. 2. Maturation stages of herring samples collected in 1970 showing maturation cycles of spring and summer–autumn spawning herring. Maturation stages are expressed in percentage of the total each month.

spawning is restricted in duration and has a peak in May. However, the autumn spawning is rather dispersed, extending from July through September with a peak in September.

Discussion — The spawning grounds of herring are spread on the Magdalen Shallows, mostly within the 50-m depth contour. The multiplicity and spreading of the spawning localities are probably adaptive for survival of eggs, compensating for the possible destruction of spawning beds

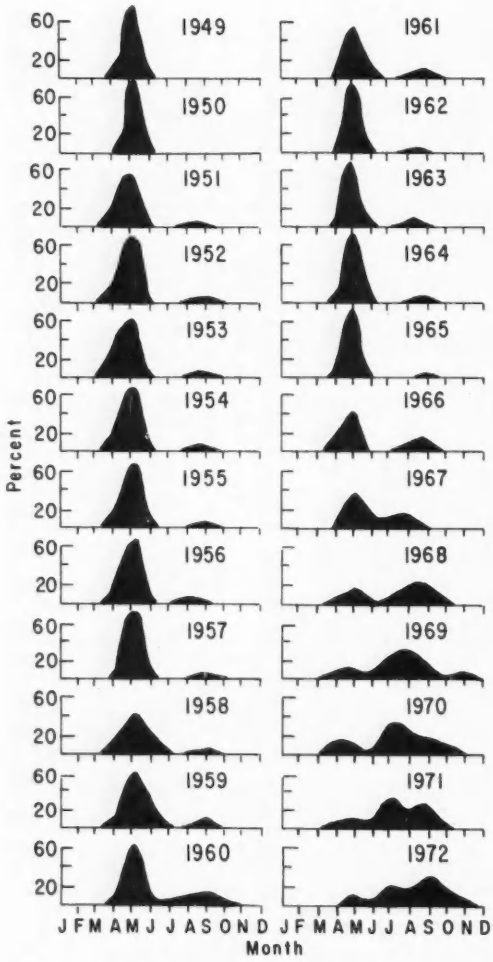

FIG. 3. Seasonal pattern of herring catches in the southern Gulf of St. Lawrence.

resulting from erratic hydrographic conditions characteristic for this area (Lauzier 1957). The location of the spawning grounds in relation to the hydrographic regime which is dominated by cyclonic surface circulation would enable the dispersal of the larval herring southwards and eastwards. This would result in minimizing competition between adults and juvenile herring. The dispersal pattern of larval herring and the detailed surface circulation in this area were described by Messieh and Kohler (1972) and Messieh (1973), respectively.

The maturation cycles of the spring and autumn spawning herring (Fig. 2) indicate little, if any, overlap between the two spawning seasons. The latter season, however, extends for 3 mo from July through September, and should be properly described as summer–autumn spawning. There are indications that the summer–autumn spawning population comprises more than one unit stock (Messieh 1973).

Analysis of herring landings in this area during the past 25 yr (Fig. 3) indicates a shift in the seasonal pattern of landings, with more autumn landings in recent years. The shift coincided with the increase in fishing effort by the mobile fishing fleet (mainly purse seiners) since 1967. Comparison of the catches by fixed gear (gillnets) in recent years with those in the forties (Leim et al. 1957) showed a similar trend, i.e. more catches from the summer–autumn spawning population than from the spring. However, the kind of data available could not explain whether the shift in herring catches reflected major changes in the relative abundance of the stocks due to intrinsic factors or merely a change in fishing effort due to vulnerability of the offshore autumn spawning population to the recently developed fishing gear. This problem warrants further investigation.

Acknowledgments — Various personnel at the Biological Station, St. Andrews, N.B., assisted in collecting and processing the data. Thanks are extended to Dr M. J. Dunbar, my thesis supervisor, and Dr R. O. Brinkhurst for granting me an educational leave during which this study was done.

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Effects of the Antimicrobial Furanace on *Fundulus heteroclitus* Embryos

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WILLIAMS, G. JR., R. C. SIMMONDS, AND J. F. BOYD. 1975. Effects of the antimicrobial Furanace on *Fundulus heteroclitus* embryos. J. Fish. Res. Board Can. 32: 69–71.

Single, 1-h treatments of five stages of *Fundulus heteroclitus* embryos with Furanace solutions (2.0, 1.0, 0.5, and 0.25 ppm) resulted in no significant increase in either mortality or anomaly rates. We conclude that a 1-h treatment with Furanace may be safely used in the media supporting fertilized eggs. Chronic exposure of *F. heteroclitus* embryos in 2.0, 6.0, and 10.0 ppm solutions results in high mortality and anomaly rates.

WILLIAMS, G. JR., R. C. SIMMONDS, AND J. F. BOYD. 1975. Effects of the antimicrobial Furanace on *Fundulus heteroclitus* embryos. J. Fish. Res. Board Can. 32: 69–71.

Des traitements uniques, d'une heure chacun, de cinq stades d'embryons de *Fundulus heteroclitus* avec des solutions de Furanace (2.0, 1.0, 0.5 et 0.25 ppm) ne produisent d'augmentation significative ni des mortalités ni des taux d'anomalies. Nous en concluons que le milieu qui supporte les oeufs fécondés peut subir sans danger un traitement d'une heure au Furanace. Une exposition chronique des embryons à des solutions de 2.0, 6.0 et 10.0 ppm résulte en des mortalités et des taux d'anomalies élevés.

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RECENT studies involving a new chemotherapeutic agent, first designated "P-7138", and subsequently named "Furanace" (Furpyrinol, Abbott Laboratories), indicated that the drug inhibits the activity of many species of bacteria pathogenic for fish (Amend and Ross 1970; Ross 1972). The drug also has antifungal activity against several strains of fungus which are not susceptible to other antibiotics (Furanace Product Profile). These investigations indicated that Furanace might be a good agent for use in prophylactic treatment of adult and embryonic fish to prevent bacterial and fungal infections.

Fundulus heteroclitus has been selected as a potential test animal species for inflight embryology experimentation in space. Occasionally, even under the optimum conditions maintained in the laboratory, bacteria or fungi contaminate the developing embryos. The infecting organisms may attack the embryo itself or the chorion and often kill the developing fish. The study reported here was undertaken to determine whether or not the drug was toxic for the unhatched fish.

Methods and materials — A breeding stock of wild *F. heteroclitus* was supplied by the National Marine Fisheries Service, Beaufort, North Carolina. The fish were maintained in a "Living Stream" at 23 C with a 16-h light and 8-h dark photoperiod (Boyd and Simmonds 1974). The breeding pairs spawned at the downstream end of the tank against a nylon mesh filter screen. Eggs were collected daily from this filter and the trough and screen which make up the filter casing. The eggs were washed with tap water, culled, staged, and treated with the Furanace solution. The adults and embryos were kept in an Instant Ocean solution (Aquarium Systems, Inc., Eastlake, Ohio) at approximately 22‰ salinity. The synthetic sea water used in these studies, and for preparation of the Furanace solutions was sterilized by filtration into a sterile flask through gridded 0.45-μ membrane filter. The solution was aseptically transferred from this container to smaller flasks under a laminar flow hood.

Four dilutions of the drug (2.0, 1.0, 0.5, 0.25 ppm) were tested on each of five stages of embryos. The

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TABLE 1. Survival of *Fundulus heteroclitus* after a 1-h treatment with Furanace.

	2.0 ppm	Controls	1.0 ppm	Controls	0.5 ppm	Controls	0.25 ppm	Controls
				Zygotes				
Number	(185)	(200)	(200)	(249)	(178)	(207)	(200)	(200)
% hatched	66.0	50.0	71.0	67.0	65.0	71.0	47.0	55.0
% mortalities	34.0[a]	50.0	29.0	33.0	35.0	29.0	53.0	45.0
% anomalies	7.0	4.0	4.0	2.0	1.0	1.0	4.0	5.0
				Blastulae				
Number	(200)	(222)	(200)	(221)	(100)	(130)	(102)	(141)
% hatched	83.5	86.5	92.5	87.8	92.0	91.5	97.1	90.8
% mortalities	16.5	13.5	7.5	12.2	8.0	8.5	2.9	9.2[a]
% anomalies	0	0	1.0	2.7	5.0	1.5	1.0	3.6
				Gastrulae				
Number	(200)	(214)	(101)	(103)	(100)	(100)	(106)	(105)
% hatched	94.0	90.4	87.1	80.6	85.0	89.0	91.5	87.6
% mortalities	6.0	9.6	12.9	19.4	15.0	11.0	8.5	12.4
% anomalies	0.5	0	1.0	2.0	1.0	2.0	2.8	0
				Neuralae				
Number	(209)	(205)	(207)	(206)	(100)	(111)	(100)	(100)
% hatched	89.9	87.8	84.5	93.2	89.0	90.9	98.0	93.0
% mortalities	10.1	12.2	15.5[a]	6.8	11.0	9.1	2.0	7.0
% anomalies	0.5	0.5	0.5	2.0	3.0	2.7	1.0	2.0
				Eyed embryos				
Number	(200)	(214)	(200)	(214)	(100)	(100)	(100)	(100)
% hatched	89.5	85.5	89.5	88.3	91.0	96.0	87.0	86.0
% mortalities	10.5	14.5	10.5	11.7	9.0	4.0	13.0	14.0
% anomalies	1.5	1.4	0	1.4	2.0	1.0	3.0	1.0

[a]Statistically significant to the 0.05 level.

stages included the zygote, the flat blastula, the gastrula, the neurala, and the fully eyed or retina pigmented as described by Armstrong and Child 1965, and Oppenheimer 1937. Zygote staged eggs were obtained by "stripping" gravid females and males (Armstrong and Child 1965). Furanace solutions were prepared at 2-wk intervals and stored in a dark cabinet. The eggs used in the short exposure tests were treated for 1 h, washed in tap water, and placed in sterile 100- × 20-mm petri dishes containing approximately 40 ml sterile Instant Ocean. Treated and control embryos were maintained in an incubator at 23 C ± 2. The embryos were checked regularly until hatching. As this study was part of an extensive program using *Fundulus*, and the number of eggs produced at any given time was insufficient to support all ongoing studies, some difficulty was encountered in obtaining the desired number of embryos at the specific stages. For this reason the number of animals per treatment group varied. Total mortalities, total eggs hatched, and the numbers and types of abnormalities were tabulated.

In addition to the treatments described above, some embryos were placed in solutions of 2.0, 6.0, and 10 ppm Furanace for periods up to 32 days.

Results and discussion — The concentrations of Furanace solutions used in the experiment were suggested by the work of Amend and Ross 1970. They concluded that columnaris disease could be eradicated from juvenile coho salmon by a single 1-h treatment of the diseased fish with a 1.0 ppm solution. Furthermore, they found that the drug was readily absorbed and eliminated, and was nontoxic to the fish. The five test stages selected were considered representative to the entire developmental process.

The results of our short exposure investigations are shown in Table 1. Chi-square analysis of these data indicated that statistically significant results were obtained in only 3 of the 20 treatment groups. Exposure of *F. heteroclitus* zygotes to the

Furanace solutions resulted in only one significant difference ($P \leq .05$) between treated and control groups. At 2.0 ppm a higher mortality was recorded in the control animals. Furanace treatment of later-staged embryos produced statistically significant ($P \leq .05$) results only in the blastula stage at the 0.25 ppm concentration (lower mortality in treated group) and in the neuralae at the 1.0 ppm concentration (higher mortality in treated group).

The apparently beneficial results of treating zygotes with 2.0 ppm solutions of Furanace is probably inaccurate. Fifty per cent of the control embryos died. In studies involving *Fundulus* we have noted that many eggs develop to blastula by parthenogenesis. Therefore, the eggs appear to be fertile, but never mature. Although the 1-h exposure of zygotes to Furanace does not necessarily increase hatchability, our data indicate no detrimental effects on mortality or anomaly rates in zygotes so exposed.

Statistically significant ($P \leq .05$) differences were observed in two other treatment groups; however, we believe these to be data artifacts. In general, we believe that our data indicate that 1-h exposure to Furanace solutions (2.0, 1.0, 0.5, and 0.25 ppm concentrations) is not harmful to *F. heteroclitus* embryos.

The growth of *Fundulus* embryos in Furanace solutions from zygote until hatching was also studied. Fifty zygotes were maintained in 2.0 ppm Furanace and incubated. Within 3 days 23 embryos were dead and only 3 were normal. Twenty-four embryos remained — all with anomalies of various types including the following: enlarged pericardium, eye deformities, malformed tails, heads, fins, and bodies, and scoliosis and lordosis. Similar results were observed in zygotes allowed to develop in 1.0 ppm Furanace solutions.

To determine the extent of chronic toxicity to older embryos, fully eyed individuals were placed in 6.0 ppm and 10.0 ppm solutions of Furanace. After 8 days in 6.0 ppm, 16 of 50 were malformed (i.e. misshaped heads, and malformed eyes). The 10.0 ppm level induced gross abnormalities and caused death to all 50 of the experimental fish. Almost all the test embryos at both concentrations had greatly reduced yolk and body size as well as other abnormalities (i.e. enlarged pericardium, reduced heart size, and enlarged eyes). No changes were apparent in the control groups.

Acknowledgments — We gratefully acknowledge Abbott Laboratories, Agricultural and Veterinary Products Division, North Chicago, Ill. for their support in supplying the Furanace required for this study.

During the period when this study was accomplished, G. Williams was a NASA–American Society for Engineering Education Summer Fellow at the Johnson Space Center, Houston, Texas.

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Inhibition of Primary Productivity through Heterotrophic Competition for Nitrate in a Stratified Estuary

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PARKER, R. R., J. SIBERT, AND T. J. BROWN. 1975. Inhibition of primary productivity through heterotrophic competition for nitrate in a stratified estuary. J. Fish. Res. Board Can. 32: 72–77.

Virtual disappearance of NO_3 from Alberni Inlet brackish water containing very sparse phytoplankton with low growth rate was documented using ^{14}C technique with chemical determinations of nutrients and chlorophyll. This phenomenon is explained by the enhancement of the heterotrophic biomass by the organic carbon-rich, nitrogen-deficient, pulpmill effluent and the consequent heterotrophic assimilation of NO_3 as a nitrogen source for protein synthesis.

PARKER, R. R., J. SIBERT, AND T. J. BROWN. 1975. Inhibition of primary productivity through heterotrophic competition for nitrate in a stratified estuary. J. Fish. Res. Board Can. 32: 72–77.

La méthode du ^{14}C et des dosages chimiques des substances nutritives et de la chlorophylle nous ont permis de démontrer la disparition pratiquement totale du NO_3 de l'eau saumâtre de l'inlet Alberni contenant un phytoplancton clairsemé et à croissante lente. Nous expliquons ce phénomène par le rehaussement de la biomasse hétérotrophe causé par l'effluent d'un moulin de pâte à papier, riche en carbone organique et déficient en azote, et par l'assimilation subséquente de NO_3 comme source d'azote dans la synthèse des protéines.

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NITRATE in the marine water underlying the halocline in Alberni Inlet, B.C. has been observed in concentrations of at least 4 μg-at N/liter (Parker et al. 1973a, b, c, d; Parker et al. 1974). Estuarine circulation with its process of entrainment (Tully 1949) would seem to assure a constant supply of NO_3 to the upper mixed layer, in addition to other sources which may exist. Toward the head of the inlet, the standing stock of phytoplankton, as measured by chlorophyll concentration is typically less than 2 μg chlorophyll/liter and usually much less, in the upper zone (Parker et al. 1973a, b, c, d; Parker et al. 1974) With this low standing crop, primary production, under the best of circumstances, is low, and the autotrophic assimilation of nitrate would also be low. Data acquired in 1970 suggest that on at least two occasions NO_3 in the upper zone was low enough to limit production. Using the ^{14}C technique, autotrophic relative growth rates at the surface were lower than would be predicted from light available on June 22, 1970 (observed $k = 0.093$, expected $k \approx 0.14$) and on August 27, 1970 (observed $k = 0.006$, expected ≈ 0.03, Parker and Sibert 1972, fig. 7). In both cases NO_3 was less than 0.5 μg-at N/liter (Parker and Sibert 1972, table 3). Apparently NO_3 was being lost from the upper zone water to an unknown sink. One possible nitrate sink is nitrogen fixation by heterotrophic organisms. The pulp mill in Port Alberni discharges large amounts of organic matter into the surface layer of Alberni Inlet and, consequently, the heterotrophic biomass in the surface layer is quite large. For example, in August 1971 the mill discharged approximately 35,000 lb/day of BOD (biochemical oxygen demand)[2] and there was a standing crop of bacteria on the order of 10^7 viable counts per liter (Parker et al. 1973).

The purpose of this report is to present and interpret data acquired to examine this problem. Two experiments are described. The first employed the ^{14}C technique to evaluate autotrophic production and measured NO_3 concentration in

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[2]BOD data courtesy of MacMillan Bloedel Ltd.

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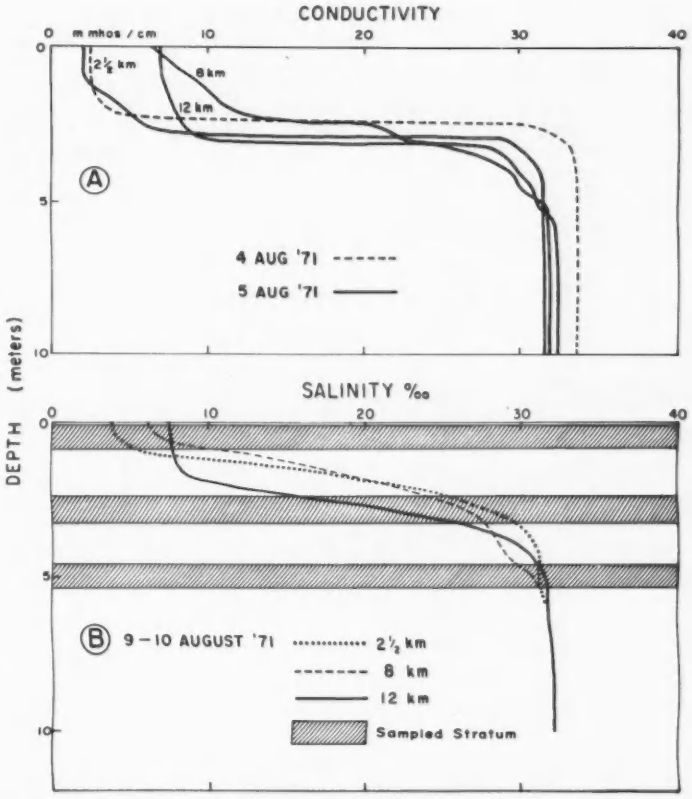

FIG. 1. Conductivity profiles from August 4–5 (*upper*) and salinity profiles from August 9–10 (*lower*) 1971, Alberni Inlet, B.C.

water strata relative to the halocline at the head of Alberni Inlet in 1971. The second experiment documented the heterotrophic consumption of nitrate in carbon-rich nitrogen-poor aliquots of sea water in 1973.

Materials and methods — A single station 2.5 km seaward of the river mouth was occupied on August 4, 1971 and three stations, at 2.5, 8, and 12 km, were occupied on August 5, 1971. Salinities were not obtained because of apparatus failure; however, the position of the halocline was located from conductivity data. Station profiles are shown in Fig. 1A. A very sharply defined halocline was evident between 2 and 3 m at all stations. Water was drawn with a van Dorn bottle from 0.5-, 3-, and 5-m depths, corresponding to the upper mixed zone, the halocline, and the top of the marine water column under the halocline. Salinity values were assumed from August 9–10, 1971 samples (Fig. 1B) for estimating total carbonate in the water samples.

Production was estimated using the ^{14}C technique, suspending the water samples in situ for incubation. Each set (station, depth) consists of a light and a dark bottle, and in one case (12-km, 0.5-m) duplicate light bottles.

Samples of water were also analyzed for nitrate, phosphate, and chlorophyll, using standard methods found in Strickland and Parsons (1968). No correction was used for chlorophyll *b* and chlorophyll *c*. In situ incubations occurred during midday, between 1000 and 1500 Pacific Standard Time. The secchi depth was 2 m at all stations. Both days were partly cloudy; however, between 26 and 42 ly/h were available at the surface and assuming an attenuation coefficient of 0.8 m^{-1} (Parker and Sibert 1972) light was adequate to allow near maximum photosynthesis at 0.5-m depth (>6 ly/h^{-1}, McAllister et al. 1964).

Dark bottles for the 3- and 5-m depths at the 8-km

TABLE 1. Production data for Alberni Inlet, August 4–5, 1971.

Station (km)	Depth (m)	Chlorophyll *a* (mg/m^3)	Carbonate[a] (mg C/m^3)	Radioactivity: Sample (dpm)	Radioactivity: control (dpm)	Incubation time (h)	Production (mg C/m^3)	Relative[b] growth (h^{-1})
Aug. 4, 1973								
2.5	0.5	1.56	5000	4185	836	3.83	1.584	0.009
	3.0	1.56	23700	1272	558	3.83	1.601	0.024
	5.0	0.22	27450	191	186	3.83	0.013	< .001
Aug. 5, 1973								
2.5	0.5	1.11	5000	1230	1167	3.95	0.030	< .001
	3.0	1.03	23700	931	680	3.95	0.563	0.005
	5.0	0.44	27450	118	196	3.95	Nil	Nil
8	0.5	2.83	6000	3586	541	3.93	1.728	0.005
	3.0	3.36	22450	523	350[c]	3.93	0.367	< .001
	5.0	0.87	27450	189	150[c]	3.93	0.101	< .001
12	0.5	2.89	8000	2069 1615	436	3.92	1.236 0.892	0.004 0.003
	3.0	2.74	16200	2833	330	3.92	3.836	0.012
	5.0	0.98	28700	184	150	3.92	0.092	< .001

[a] ΣCO_2 in mg C/m^3 = 1250 (S‰)–1130 for S > 10,
= 1000 (S‰) for S ≤ 10, salinities of August 9–10, 1971 were used.

[b] Equation (1), see text.

[c] Estimated values, see Fig. 2.

station (first experiment) were lost. Values given in Table 1 were estimated by interpolation between other dark-bottle values at the same depths at specified seaward distances. This approximation is justified on the grounds that dark-bottle uptake of ^{14}C is thought to be related to the amount of dissolved and colloidal organic material and attendant bacteria in the water (Qasim et al. 1972; Takahashi et al. 1970; Seki 1967, 1968). Most of this material in the upper portion of Alberni Inlet originates in the pulpmill waste and becomes less dense with seaward distance and with depth (Parker and Sibert 1973; Parker et al. 1973).

Relative growth rates (k) were derived from production (p) and chlorophyll data using the equation

$$k = \frac{1}{t} \ln \frac{(\text{chlorophyll})\cdot F + P}{(\text{chlorophyll})\cdot F} \qquad (1)$$

where F is the carbon:chlorophyll ratio, assumed to be 30 (Strickland 1960).

Salinity in the upper mixed layer, although not measured on August 4 and 5, 1971, was inferred from conductivity profiles not to have been much different from that recorded on August 9–10, 1971 (Fig. 1), e.g. 3.8‰ at 2.5 km, 6.2‰ at 8 km, and 7.4‰ at 12 km. In the underlying marine water (5 m) salinity was about 32‰. Corresponding NO_3 and PO_4 levels are given in Table 2C and D. Considering NO_3 and PO_4 as conservative properties, by mixing sources of NO_3 and PO_4 associated with fresh and marine water in proportions dictated by the observed salt content, it is possible to arrive at "expected" concentrations in the upper zone water. The volume of sea water being entrained is (V_e) estimated by setting S_f to zero and solving for V_e in the equations

$$S_u = \frac{V_e S_e + V_f S_f}{V_e + V_f} \qquad (2a)$$

$$V_e = \frac{S_u V_f}{S_e - S_u} \qquad (2b)$$

where S denotes the salinity of the upper (S_u), marine (S_e), and fresh (S_f) water.

The expected concentration of NO_3 is estimated by

$$N_u = \frac{V_e N_e + V_f N_f}{V_e + V_f} \qquad (3)$$

Here N_u denotes the expected concentration of NO_3 in the upper mixed layer resulting from a mix between a volume of fresh water (V_f) having a nitrate concentration (N_f) and a volume of salt water (V_e) having a nitrate concentration (N_e). Expected values are given in Table 2C. A similar exercise was carried out for phosphate and the results are shown in Table 2D.

For the second experiment, four 5.0-gal (U.S., 18.9 liters) carboys were covered to exclude light

TABLE 2. Calculations of expected nitrate and phosphate concentrations in upper zone water resulting from freshwater and marine sources. Alberni Inlet, August 4–5, 1971.

A. Fresh water	Somass River[a]	Pulpmill sewer[b]	Total
Discharge (m^3s^{-1})	70.8	2.0	V_f 72.8
NO_3 (*mg-at N/m³*)	1.91	27.4	N_f 2.62
PO_4 (*mg-at P/m³*)	0.02	11.6	P_f 0.34

B. Salt (‰)[c]	Upper zone S_u	Marine (*5 m*) S_e	Entrainment V_e
2½ km	3.8	32	9.8
8 km	6.2	32	17.5
12 km	7.4	32	21.9

	Observed		
C. NO_3(mg-at N/m^{-3})	Marine (*5 m*) N_e	Upper zone N_u	Expected N_u
2½ km (4th)	6.3	< limit	3.1
2½ km (5th)	10.5	< limit	3.6
8 km (5th)	5.6	< limit	3.2
12 km (5th)	4.6	< limit	3.1

	Observed		
D. PO_4(*mg-at P/m*$^{-3}$	Marine (*5 m*) P_e	Upper zone P_u	Expected P_u
2½ km (4th)	0.76	0.29	0.39
2½ km (5th)	0.55	0.25	0.36
8 km (5th)	0.48	0.21	0.37
12 km (5th)	0.55	0.20	0.39

[a]Source: Observations April 8, 1973 of Somass River water, previously unpublished.
[b]Source: Alpulp Division, Macmillan Bloedel Ltd., Port Alberni, B.C., same date.
[c]Source: Observations of August 9–10, 1971, previously unpublished.

completely, and filled with sea water (26.6‰ salinity) taken from the surface of Departure Bay, Nanaimo, November 19, 1973. Glucose was added in concentrations of 0, 10, 100, and 1000 μg/liter. The carboys were let stand in an unheated space. At intervals the contents were shaken and samples drawn to determine the nitrate and adenosine triphosphate (ATP) concentrations. ATP was estimated according to Holm-Hansen and Booth (1966). Results are presented in Fig. 2.

Results — Phytoplankton biomass, as indexed by chlorophyll, increased seaward in both the upper and marine water strata but not in the halocline where the maximum was found at 8 km (Table 1). Maximum production during the approximate 4-h incubation period was in the halocline stratum at the furthest seaward station (12 km), and in the surface water maximum production occurred at 8 km. The growth rates on a per hour basis were in all cases very low. From prior experience (Parker and Sibert 1972), we would expect, at the 0.5-m depth, growth rates of at least an order of magnitude larger under the ambient light and water transparency conditions. It is of particular interest that at both the 2.5-km stations and at the 12-km station the growth rates were larger in the halocline stratum than at the surface, hence light in the surface stratum could hardly have been limiting in this instance. The exception to this statement is the 3-m, 8-km set; however, the dark bottle was lost and the estimate is in some doubt.

In all cases NO_3 in the surface stratum was below our limit of certain detection (0.05 μg-at N/liter, Table 2C). Phosphate, while lower than "expected" was probably not limiting to auto-

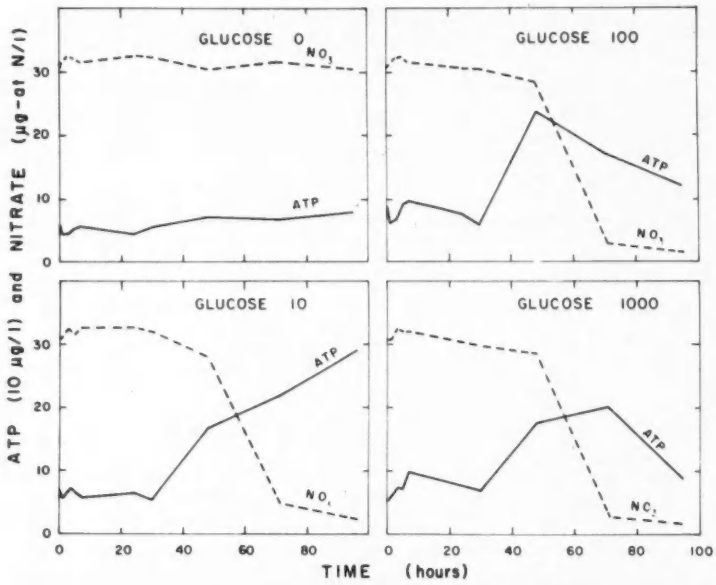

FIG. 2. Dark bottle responses of ATP and nitrate to glucose supplements in sea water.

trophic growth. In calculating the expected levels of NO_3 and PO_4 (Table 2) sources from domestic sewage were not included and hence the estimates are biased by being too low. Another source of bias is that water is deemed to mix only vertically in Table 2. Toward the head of the inlet the nitrate concentrations were generally higher at the 5-m level (Table 2). Since surface water is usually moving seaward, the mixing actually took place where higher NO_3 was available under the halocline. This also serves to bias the estimates of expected nitrate concentrations, usually by being too low. There can be little doubt that nitrate in excess of 3 mg-at m^{-1} disappeared from the upper zone.

In the heterotrophic experiments (Fig. 2) the control (0 glucose) showed little development. ATP increased slightly, presumably utilizing dissolved organic material present in the surface water and nitrate showed little change. In the presence of glucose the heterotrophic biomass increased with a corresponding decrease of nitrate. At the higher concentrations of glucose the heterotrophic biomass reached a maximum and then declined. We do not know the specific cause of the decline. These results suggest that in the presence of nitrogen-deficient organic carbon, marine heterotrophs are present which will use an inorganic source of nitrogen to synthesize protein.

Discussion — On purely physical grounds NO_3 should have been available in the upper zone water on August 4th and 5th, 1971, where none was observed. This cannot be due to autotrophic consumption of nitrate because the small standing stock produced very little. A more logical interpretation is that production was limited by the absence of nitrate. We are left with the question of its disappearance.

The ability of some heterotrophic organisms to assimilate inorganic nitrogen is well known (Nicholas 1963; Painter 1970). In the presence of an organic carbon source, nitrate is used as a nitrogen source for the synthesis of amino acids and is incorporated into the heterotrophic biomass. We suspect this process is operating in the upper zone of the Somas River estuary.

Pulp mills characteristically discharge large amounts of wood sugars deficient in nitrogen in respect to carbon. This condition favors a heterotrophic biomass capable of assimilating nitrate. This will often lead to the suppression of autotrophic production by exhaustion of the nitrate supply.

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Copper, Zinc, and Total Protein Levels in the Plasma of Sockeye Salmon (*Oncorhynchus nerka*) During their Spawning Migration[1]

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FLETCHER, G. L., E. G. WATTS, AND M. J. KING. 1975. Copper, zinc, and total protein levels in the plasma of sockeye salmon (*Oncorhynchus nerka*) during their spawning migration. J. Fish. Res. Board Can. 32: 78–82.

Concentrations of copper, zinc, and total protein were measured in the plasma of sockeye salmon (*Oncorhynchus nerka*) during their migration to the Chilko spawning grounds, British Columbia. Concentrations of both metals and total protein declined during migration. Final values for all three parameters were 20–50% of those observed in seawater animals. Concentrations of zinc and copper were positively correlated with plasma protein concentrations. An examination of the metal : protein ratios revealed that only the zinc : protein ratios declined during migration, suggesting that zinc was being removed from the plasma independent of the proteins.

FLETCHER, G. L., E. G. WATTS, AND M. J. KING. 1975. Copper, zinc, and total protein levels in the plasma of sockeye salmon (*Oncorhynchus nerka*) during their spawning migration. J. Fish. Res. Board Can. 32: 78–82.

Nous avons mesuré les concentrations de cuivre, zinc et protéines totales dans le plasma de saumons nerka (*Oncorhynchus nerka*) durant leur migration vers les frayères de la Chilko, Colombie-Britannique. Les concentrations des deux métaux et des protéines totales diminuent lors de la migration. Les valeurs finales de tous les trois paramètres sont 20–50% de celles observées chez des poissons en eau de mer. Les concentrations de zinc et de cuivre ont une corrélation positive avec celles des protéines plasmiques. Un examen des rapports métaux : protéines indique que seuls les rapports zinc : protéines diminuent au cours de la migration, ce qui donne à croire que le zinc disparaît du plasma indépendamment des protéines.

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ALTHOUGH copper and zinc are essential to fish there appears to be very little quantitative information concerning either the amounts they require or the mechanisms which regulate their levels in the body. In mammals, plasma and tissue concentrations of these metals have been correlated with the concentrations of a number of hormones in blood (Flynn et al. 1971; Sato and Henkin 1973; Evans 1973). In fish there is some evidence to suggest that plasma copper may be influenced by the thyroid (Leloup 1947; Fontaine et al. 1948) and methyltestosterone (Peterson and Shehadeh 1971).

The concentrations of a number of hormones have been shown to undergo considerable changes during the spawning migration of the salmon (see Idler 1973; Watts et al. 1974). In view of the suggested role of hormones in the regulation of copper and zinc metabolism, the present study was carried out to describe the changes in copper and zinc occurring in the plasma of sockeye salmon during spawning migration.

In mammals, most if not all of the plasma copper and zinc is believed to be bound to the plasma proteins (Vallee 1959; Evans 1973). Therefore, plasma protein changes were also followed in the migrating salmon in order to relate them to the changes in copper and zinc.

Materials and methods — Sockeye salmon (*Oncorhynchus nerka*) were caught at three points along their migratory route to the Chilko River (British Columbia) spawning grounds. The first point was in sea water off Lummi Island, Washington State, USA, 56 km from the mouth of the Fraser River where two collections were made: 1) July 23–24, 1971 (early sea water) consisting of several races of sockeye salmon headed for a number of spawning grounds, and 2) August 6, 1971 (peak sea water) consisting of salmon migrating towards the Chilko spawning grounds. The second group (freshwater arrival sockeye) was sampled at Chilko Lake. Samples were col-

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lected on two occasions from this site: 1) August 17, 1971 when the salmon were just beginning to arrive at the lake (early freshwater arrival) and 2) August 26, 1971 when the majority of the population was arriving. The third sampling site (September 22, 1971) was on the spawning grounds of Chilko River at the outlet of Chilko Lake.

Salmon were caught by reefnet at the seawater site and by beach seine at the freshwater site. The fish were stunned by a blow on the head and the blood samples (approximately 40 ml) collected from a caudal blood vessel using heparinized plastic syringes. Blood sampling was completed within 5 min of capture. Samples were stored on ice until centrifuged (within 20–30 min of collection). Plasma protein determinations were carried out immediately following centrifugation and the remaining plasma (approximately 20 ml) was frozen and stored at –20 C.

The total body weight and gonad weight of each fish were measured and the gonad-somatic (GSI) was calculated as follows:

$$\text{GSI} = \frac{\text{gonad wt (g)} \times 100}{\text{total body wt (g)}}$$

Spawning female sockeye were divided into three groups: 0% spawned or prespawning (sexually mature with egg case intact), 50% spawned (ovulated with eggs free in the body cavity), and 100% spawned or postspawned (few or no eggs remaining in the body cavity). Further details of the salmon used in this study can be obtained from Watts (1973).

Plasma copper and zinc concentrations were determined (January 1974) by atomic absorption spectrophotometry (Varian-Tectron Model AA-5 coupled to a Varian A-25 recorder). Plasma (0.3-ml) samples were precipitated with 1.5 ml of 6% trichloroacetic acid (TCA) and both metals were determined in the resulting supernatant using an oxidizing air–acetylene flame. Standard solutions were prepared in 5% TCA, (Cu 20–100 μg/100 ml, Zn 100–600 μg/100 ml). Wavelengths and slit-widths were, respectively, set as follows: Cu 324.75 nM and 50 μ, Zn 213.86 nM and 60 μ. Total plasma proteins were determined using a TS-Meter (American Optical Instrument Company, Model 10400). No corrections were made for the changing salt content of the migrating salmon plasma; therefore, the protein values obtained have an error of approximately $\pm$ 0.2–0.3 g/100 ml.

Comparisons between groups were made using Student's *t*-test and a probability level of <0.05 was taken as significant. To facilitate comparisons between groups, some of the data are presented in the form of bar graphs, showing means $\pm$ 2 SE which indicates the 95% confidence limits of the individual groups.

Results — During the spawning migration the female GSI rose from a mean of 3.24% in sea water to 14.9% immediately prior to spawning. In contrast the male GSI showed no significant trends during the same period (Table 1).

Copper concentrations in the plasma declined throughout the migration, resulting in values at spawning that were approximately half of those observed in seawater animals. Most of this decline appeared to take place in spawning fish. No significant differences in copper concentrations were observed between the sexes (Fig. 1).

The plasma zinc concentrations also dropped during migration, with the spawning fish having values which were 20–25% of those recorded for the seawater animals. In contrast to copper, most of the change in zinc concentration appeared to take place during the transition from sea water to fresh water. Apart from early freshwater and spawning fish, the concentrations of zinc in the male sockeye were significantly higher than those found in the females (Fig. 1).

Plasma protein concentrations declined from 8–9 g% in the seawater salmon to approximately 2–4 g% in the spawning animals (Fig. 2). The decline in the males appeared to be more rapid than in the females for the males had significantly lower concentrations of protein than the females at the freshwater, nonspawning stages ($P<0.05$).

The concentrations of copper and zinc were positively correlated with protein concentrations

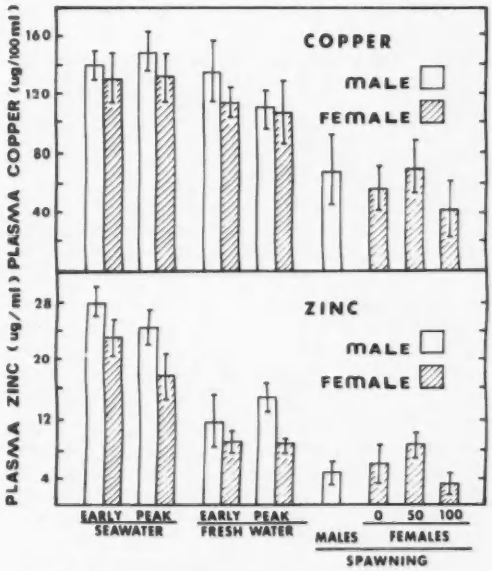

FIG. 1. Changes in plasma concentrations of copper and zinc during the spawning migration of sockeye salmon (*Oncorhynchus nerka*). The early and peak groups refer to groups of salmon caught during the early and peak times of migration.

TABLE 1. Changes in the copper:protein and zinc:protein ratios and the gonad-somatic index during the Chilko sockeye salmon (*Oncorhynchus nerka*) spawning migration 1971. Sockeye salmon were caught on the dates indicated. Spawning females were divided into three groups: 0% = prespawning, 50% = ovulated, 100% = postspawned. All values are expressed as means ± 1 SE. N = number of samples.

	Sea water		Fresh water		Spawning Sept. 22			
	July 23	Aug. 6	Aug. 17	Aug. 26	♂	♀		
						0%	50%	100%
				♂				
N	14	23	11	14	14			
Gonad (g/100 g body wt)	2.14 ±0.232	3.09 ±0.189	3.20 ±0.356	2.96 ±0.105	2.62 ±0.201			
Zn^{++} (μg/g protein)	316 ±21.7	311 ±14.2	218 ±21.0	266 ±13.5	174 ±18.1			
Cu^{++} (μg/g protein)	15.9 ±1.10	19.5 ±1.11	26.9 ±2.40	19.9 ±1.00	25.9 ±2.60			
				♀				
N	11	21	18	15		11	8	10
Gonad (g/100 g body wt)	3.24 ±0.478	4.31 ±0.217	10.1 ±0.285	10.3 ±0.490		14.9 ±0.314	7.99 ±1.54	1.13 ±0.102
Zn^{++} (μg/g protein)	282 ±22.2	205 ±15.4	142 ±12.7	131 ±6.12		135 ±19.2	178 ±19.5	213 ±50.7
Cu^{++} (μg/g protein)	16.3 ±1.25	17.3 ±1.30	18.0 ±1.0	16.4 ±2.0		15.1 ±2.1	17.2 ±1.50	29.3 ±7.12

in each of the spawning groups (males, females 0%, 50%, 100%) ($P<0.01$ in each group). Although not statistically significant the same correlation appeared to be present in the nonspawning animals. For example, two peak seawater female fish had very low copper and zinc concentrations 1) Cu 60 μg/100 ml, Zn 0.9 μg/ml and 2) Cu 66 μg/100 ml, Zn 1.1 μg/ml) compared with the means for these groups (Cu 131 μg/100 ml, Zn 17.5 μg/ml). These fish also had low protein concentrations (1 = 1.8 g/100 ml, 2 = 3.1 g/100 ml) compared to the mean of 8.07 g/100 ml.

The observed correlations between the plasma proteins and the metals and the simultaneous changes in all of these parameters during the migration prompted the examination of changes in metal:protein ratios (micrograms metal per gram protein) (Table 1). Zinc:protein ratios in the males declined significantly ($P<0.05$) during the transition from sea water to fresh water, and from the peak freshwater to the spawning stages. The same trend was evident in the females, with the lowest concentrations appearing at the peak freshwater and 0% spawning stages. During and following spawning the zinc:protein ratios in the females approached seawater values. However, due to the large variation in the 100% spawning fish, the observed difference between the means of the 0% and the 100% spawning fish was not significant. The decline in the zinc:protein ratios of the females appeared to be more rapid than that observed for the males, because, prior to spawning the males had significantly ($P<0.05$) higher ratios than the females for all of the groups except the early seawater animals.

Copper:protein ratios did not decline during the spawning migration (Table 1). In the males the highest values ($P<0.05$) were observed in early freshwater and spawning animals. No significant differences were apparent between any of the female groups. In addition, the copper:protein ratios were similar for males and females.

Discussion — The changes observed in plasma copper and zinc during spawning migration are difficult to interpret due to our lack of quantitative information concerning the concentrations of these metals in salmon tissues. However, there is sufficient information on other fishes to form a preliminary picture of the copper and zinc dynamics during spawning migration.

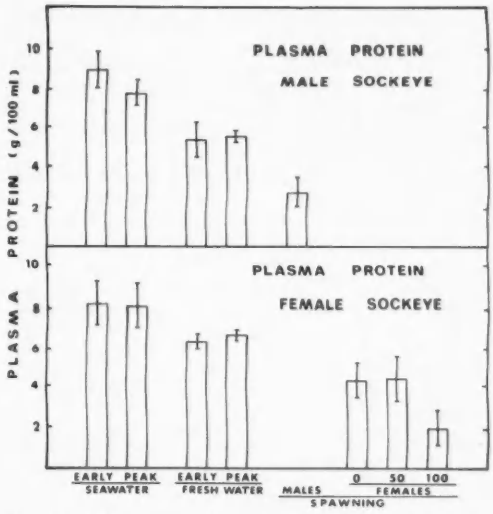

FIG. 2. Changes in plasma concentration of protein during the spawning migration of male and female sockeye salmon.

Evidence to date indicates that fish normally obtain zinc from dietary sources rather than direct accumulation from water (Hoss 1964; Pentreath 1973a, 1973b). Low concentrations of copper in sea water (approximately 10 μg/liter, Goldberg 1963) suggest that food is also the major source of this element. The sockeye salmon does not eat once it has initiated the spawning migration (Idler and Clemens 1959). Therefore, it must store copper and zinc prior to initiation of migration.

Fish skin and gonads have been reported to contain high concentrations of zinc (Vinogradov 1953; Pentreath 1973a). Therefore, the increase in skin thickness (Robertson and Wexler 1960) and ovary size during migration suggests that a store (nondietary) of zinc must be available. Although there appears to be less copper than zinc in the gonads (Vinogradov 1953) a store of copper would also be necessary for the developing sockeye ovary. The muscle, and bony tissue (skeleton, scales etc.) of teleosts contain relatively large amounts of zinc and copper (Vinogradov 1953; Pentreath 1973a) and because these tissues change considerably during spawning migration, they could play a role in trace element storage (van Someren 1937; Tchernavin 1938; Robertson and Wexler 1960; Vladykov 1962).

The decline in plasma zinc and copper during the spawning migration is consistent with the idea that they were removed from the plasma by tissues requiring them (thickening skin, bone and gonad development, see Watts 1973). However, because these metals are bound to plasma proteins (Vallee 1959; Evans 1973), this interpretation is complicated by the simultaneous decline in plasma proteins. In addition, hematocrits and plasma Na^+ also decreased during migration (Watts 1973). The reduction in plasma proteins indicates that the decline in copper and zinc could have been passive, and controlled only by the processes that resulted in the reduced protein concentrations (hemodilution, protein catabolism, and/or liver degeneration, for references see Watts 1973).

Metal:protein ratios were examined to determine whether or not copper and zinc were disappearing from the plasma independent of the plasma proteins. The results indicate that zinc was lost from the plasma of both sexes at a greater rate than the plasma proteins and therefore could have been controlled by some specific mechanism. In contrast the copper:protein ratios did not decline during migration. In fact there was a significant rise at the early freshwater and spawning stages. The apparent rise in metal:protein ratios in the spawned females may have been due to a reduction in tissue requirements, or to a nonlinear relationship between the plasma proteins and the metals.

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Above-ground Production of Marsh Cordgrass (*Spartina alterniflora*) Near the Northern End of its Range

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HATCHER, B. G., AND K. H. MANN. 1975. Above-ground production of marsh cordgrass (*Spartina alterniflora*) near the northern end of its range. J. Fish. Res. Board Can. 32: 83–87.

In Petpeswick Inlet, Nova Scotia, the above-ground portion of *Spartina alterniflora* lost an estimated 152 g dry weight m^{-2} of dead leaves during the growing season and reached an average biomass of 558 g dry weight m^{-2} at the end of the growing season. The total production of 710 g dry weight is higher than that recorded at many sites between Nova Scotia and North Carolina, in spite of the fact that in Nova Scotia the species is near the northern end of its range.

HATCHER, B. G., AND K. H. MANN. 1975. Above-ground production of marsh cordgrass (*Spartina alterniflora*) near the northern end of its range. J. Fish. Res. Board Can. 32: 83–87.

A Petpeswick Inlet, Nouvelle-Ecosse, la partie aérienne de *Spartina alterniflora* subit, durant sa période de croissance, des pertes, sous forme de feuilles mortes, estimées à 152 g poids sec m^{-2} et atteint, à la fin de cette période, une biomasse moyenne de 558 g poids sec m^{-2}. La production totale de 710 g, poids sec, est supérieure à celle rapportée pour d'autres régions situées entre la Nouvelle-Ecosse et la Caroline du Nord, bien que la Nouvelle-Ecosse soit dans l'aire la plus septentrionale de l'espèce.

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IT has gradually become apparent that marine macrophytes in the intertidal and shallow subtidal coastal areas are extremely productive and play important roles in supporting detritus-based food chains (Teal 1962; Kanwisher 1966; Mann 1973). On the eastern seaboard of North America two main types of community are involved. On rocky shores the dominant community consists of large algae, of which the most productive are the kelps (Laminariales). On sedimented shores there frequently develops a salt marsh community of angiosperms, with *Spartina* dominating in the intertidal and *Zostera* in the subtidal.

On the Atlantic coast of Nova Scotia *Spartina* marshes are confined to sheltered estuaries and inlets. Moreover, the St. Lawrence estuary, just north of Nova Scotia, marks the limit of any important development of *Spartina* marshes (Teal and Teal 1969). Hence, this study of the productivity of *Spartina alterniflora* in a Nova Scotian estuary is of interest in showing the performance of the species near the northern end of its range.

Methods — Production was determined by following changes in living and dead plant biomass during the growing season (May–August), in Petpeswick Inlet, N.S. (44°45′N, 63°10′W) (Fig. 1). *Spartina alterniflora* is well suited to this method of study, because the growing season is well defined, grazing on the plants is minimal (Teal 1962), and the leaves that die during the growing season remain attached to the plant sufficiently long to be easily enumerated. Attention was confined to aerial parts of the plant, since the annual cycle of translocation between leaves and rhizomes makes it almost impossible to make a separate estimate of below-ground production (Lack 1973). The method has the advantage that other workers have used it to obtain data with which the results of this study may be compared (e.g. Smalley 1958; Williams and Murdoch 1969; Odum and Fanning 1973).

A sampling program extending from May 1, 1971 to August 31, 1971 was designed to give information on the loss of dead material during the growing season, and on the time at which peak biomass was

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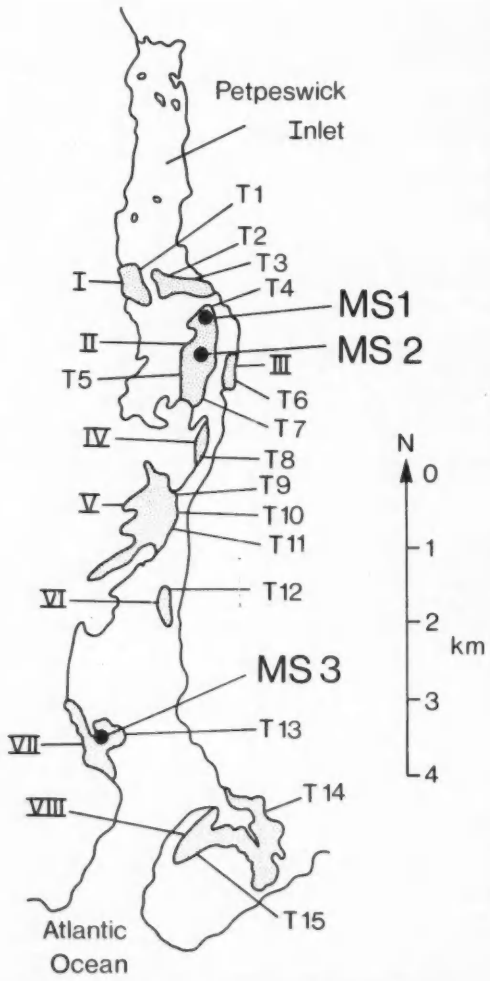

FIG. 1. Sketch map of Petpeswick Inlet, N.S., showing major patches of *Spartina*, I–VIII; ends of transects T 1–T 15, and monitoring stations MS 1–MS 3. Transects were laid out at right angles to seaward edge of *Spartina* patches, to give proportional representation of vegetation types.

reached. At the time of peak biomass an extensive sampling program was carried out to give representative biomass figures for each zone of *S. alterniflora* in the inlet.

Three monitoring stations (Fig. 1) were chosen as being representative of the three ecotypes of *Spartina*, namely the tall form which occurs at the edges and on the levees of major creek channels, the medium form which occurs in the middle marsh between small creeks and salt pans, and lastly the short *Spartina* which occurs in low lying areas that are flooded for a larger proportion of the tidal cycle, and which have poorer drainage. At each monitoring station 20 plants of various heights were marked with numbered tags. The height of each plant was recorded once in June, twice in July, and 3 times in August. At the same time a record was made of the total number of green leaves and the number of brown decaying leaves on each plant. On the last sampling date the tagged plants were harvested, dried at 105 C for 24 h, and weighed. Five other plants of a range of sizes were harvested from near each monitoring station and used to determine the average weight per leaf for plants of different heights. This information was then used to calculate the biomass of leaves lost by each marked plant prior to each sampling date, by multiplying the average leaf weight from a plant of similar height, by the number of leaves lost in each sampling interval. Summation for all sampling intervals gave the figure for biomass lost prior to time of peak biomass.

Peak biomass was determined in the last 2 wk of August by taking quadrat samples of area 0.05 m^2 at approximately 10-m intervals along 15 transects chosen to be as representative as possible of all areas of *Spartina* in the estuary. There were altogether 295 samples. Samples were stripped of epiphytes, washed, shaken, weighed fresh, and aliquots were dried and reweighed. For each vegetation type, production was calculated as peak biomass plus the biomass lost prior to final sampling.

Aerial photographs were taken from 1500 m at low tide and used to determine, on the mosaic, the area of each discrete patch of *Spartina* by planimetry. Error in determinations of area was estimated at ± 0.5%. By multiplying area of patch and production per unit area we obtained primary production for each patch, expressed as fresh weight and dry weight. For comparison with other data, carbon content was assumed to be 40.77% of dry weight (Burkholder and Bornside 1957) and calorific value 4.10 kcal/gram dry weight (Odum and Fanning 1973).

Results — Changes in plant height during the growing season are shown on the left of Fig. 2. By mid-August plants at Stations 2 and 3 had stopped growing and were in flower. Plants at Station 1 continued to grow during the week August 11th–18th, but flowering had begun and it is reasonable to assume that growth would then cease. The difference in height between the three ecological types of *S. alterniflora* is clearly shown.

From the 30 plants taken near each monitoring station during the growing season, the following regressions of biomass on height were obtained:

Station 1; $w = .009\ h^{1.464}$, $r = 0.868$
Station 2; $w = .003\ h^{1.848}$, $r = 0.916$
Station 3; $w = .001\ h^{2.000}$, $r = 0.966$

where w = dry weight and h = height in centimeters.

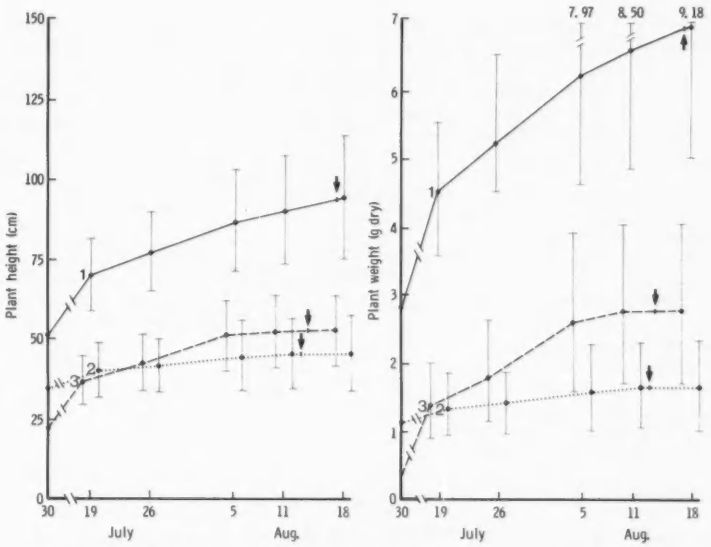

FIG. 2. *Left, Spartina alterniflora* mean plant heights on different dates at stations 1 (tall), 2 (short), and 3 (medium) in Petpeswick Inlet, N.S. *Right,* Mean plants biomass at various dates. Vertical lines are ranges of data. Arrows indicate time of start of flowering.

These were used to convert the height curves on the left of Fig. 2 to the biomass curves on the right of that figure. The calculations of leaf loss showed that the biomass lost during the growing season was 23.3% of final weight in Station 1, 27.1% in Station 2, and 35.1% in Station 3. In calculating total loss, one of these percentages was applied to each vegetation type, as appropriate.

Net production for the growing season is shown separately for each transect in Table 1. In Table 2 is shown the application of transect data to the vegetation patches I–VIII whose area had been determined. The sum of productivity in all areas divided by the total area gives the average production figure, 710 g dry weight m^{-2} yr^{-1}. This corresponds to approximately 2786 g fresh weight, 289 g C, or 2911 kcal m^{-2}. The average standing biomass at the end of the growing season was 558 g dry weight m^{-2}.

TABLE 1. *Spartina alterniflora* — production, per unit quadrat sample, averaged for each transect.

Transect	No. of samples	Production (g *dry wt* 0.05 m^{-2} yr^{-1})
1	12	43.78 ± 24.17
2	11	40.11 ± 18.74
3	5	29.55 ± 7.47
4	20	37.00 ± 18.22
5	11	33.09 ± 11.38
6	9	33.41 ± 9.58
7	25	30.73 ± 9.72
8	27	22.39 ± 9.98
9	27	33.35 ± 12.33
10	17	37.26 ± 11.98
11	35	36.04 ± 10.23
12	14	35.02 ± 12.42
13	33	36.64 ± 14.38
14	22	29.00 ± 10.69
15	27	47.23 ± 16.92

Discussion — In Fig. 3 the results of this study are compared with studies at other sites on the Atlantic coast of North America. Particular care has been taken to make the list comprehensive, to make careful conversions of productivity expressed in different units, and to note the degree to which variation between ecological types has been taken into account. Clearly, there is a tendency for the productivity of *S. alterniflora* to decrease with increasing latitude. Nevertheless, there are sites in North Carolina where the productivity is no greater than in Nova Scotia, and it is clear that factors which are unrelated to latitude, such as availability of nutrients, are having a marked influence on the production.

TABLE 2. Production of *Spartina alterniflora* in whole inlet, weighted for area occupied by each ecotype.

Patch no.	Area in m^2	Transects included	Production per 0.05 m^2 quadrat (g *dry wt*)	Mean production on geographical area (g *dry wt* m^{-2})	Total production area (*kg dry wt*)
I	90578	1	43.78		
		2	40.11	756.26	68.50
		3	29.55		
II	237059	4	37.00		
		5	33.09	672.13	159.34
		7	30.73		
III	32551	6	33.41	668.20	21.75
IV	7076	8	22.39	447.80	3.17
V	243427	9	33.35		
		10	37.26	711.00	173.08
		11	36.04		
VI	9199	12	33.02	660.40	6.08
VII	58026	13	36.64	732.80	42.52
VIII	135866	14	29.00	762.30	103.57
		15	47.23		
Totals	813782[a]				578.01[a]

[a]Average productivity from columns 2 and 6 = 710 g dry weight m^{-2} y^{-1}.

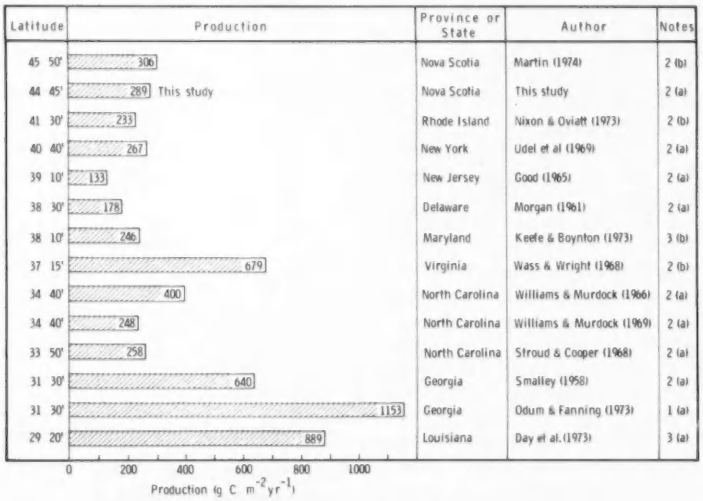
Latitude
Production
Province or State
Author
Notes
45 50' 306 Nova Scotia Martin (1974) 2 (b)
44 45' 289 This study Nova Scotia This study 2 (a)
41 30' 233 Rhode Island Nixon & Oviatt (1973) 2 (b)
40 40' 267 New York Udel et al (1969) 2 (a)
39 10' 133 New Jersey Good (1965) 2 (a)
38 30' 178 Delaware Morgan (1961) 2 (a)
38 10' 246 Maryland Keefe & Boynton (1973) 3 (b)
37 15' 679 Virginia Wass & Wright (1968) 2 (b)
34 40' 400 North Carolina Williams & Murdock (1966) 2 (a)
34 40' 248 North Carolina Williams & Murdock (1969) 2 (a)
33 50' 258 North Carolina Stroud & Cooper (1968) 2 (a)
31 30' 640 Georgia Smalley (1958) 2 (a)
31 30' 1153 Georgia Odum & Fanning (1973) 1 (a)
29 20' 889 Louisiana Day et al. (1973) 3 (a)
0 200 400 600 800 1000
Production (g C m^{-2} yr^{-1})

FIG. 3. Productivity of *S. alterniflora* at various sites on the Atlantic coast of North America. Notes in right hand column: 1, tall form under optimal conditions; 2, average of range of ecotypes, weighted according to percentage occurrence; 3, arithmetic mean of production in different ecotypes; a, Accounting for losses during the growing season; b, Losses during the growing season assumed to be 25% of final biomass.

The results obtained in this study are confirmed by those of Martin (1974), who worked on the northwestern shore of Nova Scotia which borders on the Gulf of St. Lawrence. In both these instances, the productivity of *Spartina alterniflora* was as high, or higher than on sites in Maryland, Delaware, New Jersey, New York, and Rhode Island, and this in spite of the fact that it is near the northern limit of its range.

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Hybridization in Sunfishes (*Lepomis*, Centrarchidae) Based on Time-Growth and Static Allometry

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MISRA, R. K. 1975. Hybridization in sunfishes (*Lepomis*, Centrarchidae) based on time-growth and static allometry. J. Fish. Res. Board Can. 32: 88–91.

A statistical method of analyzing for hybridization based on exponential growth curves is presented. It is pointed out that with "truly cross-sectional data" such as those on the sunfishes (genus *Lepomis*) reported here, it is possible to analyze for hybridization based on static variations separately from that based on the average growths of populations. The technique of statistical linear comparisons is extended to analyze for the degree of intermediacy of the hybrids as an alternative to the hybrid index approach. Applications of the statistical method of analyzing for hybridization based on the constants of exponential curves and of the method based on static allometry are shown on a real set of data for the first time.

MISRA, R. K. 1975. Hybridization in sunfishes (*Lepomis*, Centrarchidae) based on time-growth and static allometry. J. Fish. Res. Board Can. 32: 88–91.

Nous décrivons une méthode statistique de mesure d'hybridation fondée sur les courbes de croissance exponentielles. Nous faisons remarquer qu'avec des « données véritablement représentatives », comme celles des crapets (genre *Lepomis*) que nous reproduisons ici, il est possible de mesurer l'hybridation basée sur des variations statiques, séparément de celle qui est fondée sur la croissance moyenne des populations. Nous appliquons la méthode des comparaisons linéaires statistiques à l'analyse du degré de caractères intermédiaires des hybrides, comme alternative de la méthode de l'indice d'hybride. Pour la première fois, on démontre, sur une série de données réelles, les applications de la méthode statistique de mesure d'hybridation basée sur les constantes de courbes exponentielles et les applications de la méthode basée sur l'allométrie statique.

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OFTEN an objective of studying hybridization is to estimate the degree of intermediacy of suspected hybrids. A formula for "hybrid index," developed mainly by Hubbs and Kuronuma (1942) and Hubbs et al. (1943) has frequently been used to estimate the degree of intermediacy of suspected hybrids and to study the mode of inheritance. Misra (1972) pointed out the need for analyzing for hybridization on the basis of the parameters of a growth curve of the von Bertalanffy type. This paper is concerned with hybridization based on the following aspects of growth phenomena: (i) Brett et al. (1969) point out that (a) conditional to environmental control and in the absence of limiting factors, growth is a multiplicative process, that, in the early stages of life, often follows an exponential curve, and (b) under the influence of apparent inhibition with age its overall configuration tends to follow the sigmoid shape of a logistic curve when the specific growth rate declines progressively with increasing size. The general equation for the exponential growth is

$$Y = ce^{\gamma t}$$

expressing size Y as the exponential function of time, t. In this equation "e" is the base of natural logarithms. Constant "γ" which is genetically controlled, is known as the "specific growth rate" and measures the rate of increase in Y (on the logarithmic scale) with age. The sunfish data of the present study did not fit an equation of the von Bertalanffy type, but may be explained adequately on the basis of the exponential equation as will be evident from the analysis presented later. In this case it is only appropriate to analyze hybrid indices that are based on the parameters of the exponential equation. (ii) Specimens collected at a freshwater source often belong to different

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age-groups. Each individual is measured just once for one character. Data of this type are known as "truly cross-sectional" (Cock 1966), when an independent criterion of age is available for individuals. Individuals of a given age-group provide data that are "static" (Cock 1966). Cock (1966) also points out that analysis of cross-sectional data yields information on the average growth of a population, whereas that of static data yields information on the variation in body form without regard to growth. Misra (1973) pointed out that hybrid indices for the static variation can be formulated for the parameters of the simple allometry relation, $Y = BX^K$ (particularly for the constant of allomorphosis, K) between two body-parts, X and Y, of individuals.

This paper presents a methodological analysis for hybridization in the sunfishes (genus *Lepomis*, Centrarchidae) of Pinehurst Lake, Brant County, Ontario, Canada, based on time-growth and static allometry parameters.

Materials and methods — Fish were classified into bluegill (*Lepomis macrochirus*), pumpkinseed (*L. gibbosus*), and an intermediate group reported as bluegill × pumpkinseed hybrids by Keenleyside et al. (1973). Their ages were determined as described previously by Misra and Holdsworth (1972). It is known (Huxley 1932) that if X and Y grew exponentially with time, they will be related by the equation $Y = BX^K$ of simple allometry. The coefficient of cross-sectional allometry, K, is then equal to the ratio of the specific growth constants of the exponential growth equations for the two characters. In view of this, data on the standard length (X) and the body depth (Y) measured (in millimeters) on each individual are analyzed for this paper, so that a projection of this study to the level of the cross-sectional allometry discussed by Misra and Holdsworth (1972) can be appraised.

Results — Exponential growth — Analysis of the Y-data was considered first, followed by the analysis of the X-data done similarly. Logarithmic transformation of the exponential equation yields the linear equation,

$$\ln Y = \ln C + \gamma t$$

where "ln" denotes natural logarithm. For this analysis ln Y (ln X) was designated as y (x). Age t was expressed in years and the following abbreviations and notations were used;

P(B or H): pumpkinseeds (bluegills or hybrids)
$Y_{ij}(x_{ij})$: mean of $y(x)$ values of individuals of age "j" in sample "i" (i = 1, 2, 3 for P, B, and H, respectively)
n_{ij}: number of individuals of age "j" in sample "i"
$\gamma_{iy}(\gamma_{ix})$: estimate of γ for character $y(x)$ of sample "i"
df: degrees of freedom
ms: mean square
F: variance ratio
ANOVA: analysis of variance
r: coefficient of correlation between y and t values.

Total numbers of individuals measured were 83 of P, 91 of B, and 91 of H. Values of n_{ij}, y_{ij}, and x_{ij} (the latter two expressed in common logarithms) are shown in table 1 of Misra and Holdsworth (1972). Constant γ of the exponential growth curve provides an important criterion for comparing populations. Biologically meaningful interpretation of the constant C of the exponential equation (and the constant B of simple allometry equation) is usually of severely restricted scope (Cock 1966; Gould 1966). Analysis of the specific growth constant γ alone was therefore considered.

For each sample γ was estimated as the coefficient of linear regression of y on t. Estimates of γ_{iy} and its standard error were 0.2083 ± 0.00825 for P, 0.2442 ± 0.00707 for B, and 0.2440 ± 0.00680 for H. Fractions of the total variation of y, expressed in percent as 100 r_i^2, showed that 98.8–99.5% of variations in the data for P, B, and H were explained by the linear regressions. This indicated that the straight line fit to each sample was excellent. Error msy based on large df (of 259) was obtained by pooling these residual variations with the variations within ages and used to estimate the standard error of γ_{iy}.

Mean square for the difference between fitting a separate line to each of the three samples P, B, and H and a single line to all three samples was significant ($F = 6.94$, df = 2,259). The three populations thus differed in their γ-values. Linear comparisons (see Snedecor and Cochran 1967, p. 391) among these γ-values were then set (a) in pairs, to find exactly where the differences occurred and (b) in appropriate combinations expressing any desired degree of intermediacy of the hybrids, and tested for significance by F-tests. The hybrids and the bluegills each differed from the pumpkinseeds. It was noted that H was not intermediate between the two parents, but closer to the bluegills. In fact the specific growth rates of B and H did not differ significantly.

Analysis of x-data was done in the same way and the results were similar to those for y-data. The order of γ_{ix} was the same as for γ_{iy}, i.e. highest specific growth rate for B, lowest for P and H in between. The range of γ_{ix} was 0.2023–0.1773 or 0.2050. This is small. Even so the

differences between B and P and between H and P were still significant. Again B and H did not differ in their γ_{ix} values.

Static allometric growth — Logarithmic transformation of the equation of simple allometry yields a linear equation, $y = \ln B + Kx$. Numerous cases are known in the literature (Cock 1966; Gould 1966) where differences in K values were used as criteria to distinguish biological populations. The three populations P, B, and H were therefore compared with regard to their coefficients of allomorphosis, K.

Constant K was estimated as the least squares coefficient of regression of y on x. Modifications of this method (Cock 1966; Misra and Reeve 1964) have sometimes been employed, but no method has been found entirely satisfactory. Least squares regressions estimate the true "functional relationship" when x and y are highly correlated but not in general. In the present study the least squares regression method is adequate as x and y are highly correlated and the objective of the study is to compare the different fish populations.

It may be that the K value of each age-group is adjusted to produce proportions adaptive in its size range, and change of shape may take place among groups. These hypotheses were tested by ANOVA which showed no significant differences among regression coefficients of 15 age-groups of P, B, and H, when the samples were analyzed collectively ($F = 0.52$, df = 13,233) as well as individually ($F = 0.42$, df = 4,233 for P; $F = 0.81$, df = 4,233 for B and $F = 0.38$, df = 5,233 for H). Average K values for P, B, and H did not differ significantly ($F = 1.17$, df = 2,246). Estimates of K_i and their standard errors (based on a single line fitted to all samples) were 1.0969 ± 0.06279 for P, 1.1799 ± 0.05564 for B, and 1.2161 ± 0.04612 for H. In view of this result linear comparison analysis to test for the degree of intermediacy of H was considered unnecessary.

Discussion — The quantitative study of hybridization presented here incorporates data sampled over a range of age-classes rather than from a single age-class. The analyses showed that the hybrids were not exactly intermediate between the pumpkinseeds and the bluegills. Intermediate positions, other than the exact one, show various stages of incomplete dominance (Misra and Holdsworth 1972).

Allometric constants are particularly useful in an analysis for hybridization where fitness relationships of the parental populations and their hybrids have a vital role to play. Evidence to this effect comes from a growth study on leg-size in *Gerris lacustris* reported by Misra (1965). The author gave a method of estimating heritability (i.e. proportion of the total phenotypic variation that is due to additive genetic effects) of K for the leg-size, which was significant but low as is usually the case with metric characters which are major components of fitness (see Falconer 1961). In the analyses presented here specific growth constants for H exceed those for P and do not differ significantly from the corresponding constants for B. Similarity of patterns for B and H due to the constants of allomorphosis and their disparity with that for P were observed when the null hypotheses: $K_i = 1$, $i = 1, 2, 3$ of isogonic growth (Cock 1966) of the body depth, were accepted (based on t-test) for P, but not for B and H that showed "hypergonic" growth ($K_i > 1$). The increase in body bulk with body length is spread to relatively greater body depths in individuals of B and H. The increase in size and the adaptation of new proportions in the hybrids may induce the development of new functions. As fishes have an intrinsic capacity to alter their growth rates with the changing environment, a higher value for a growth constant for the hybrids relative to their parents may be a reflection of a suitable environment and of their better fitness. Hypergonic growth of the hybrids and the observation that the means of body length and body depth of the largest hybrids (i.e. individuals of age 6) were higher than those of the largest individuals (of age 5) of P and B, indicated that the hybrids may have reached their maximum size.

Hybrid vigor was thus evident and the complete genetic dominance of one parent (the bluegills) indicated. As parental populations are relatively close phylogenetically (i.e. no well-developed postmating isolating mechanisms), nonadditive genetic factors may have considerable importance in the genetic control of allometric patterns concerning hybridization and in the alterations of rate genes. Misra and Holdsworth (1972) provided other information indicating high fitness of the hybrids. These authors also presented evidence indicating the occurrence of introgression of pumpkinseed genes into bluegill population via backcrossing of the hybrids with bluegills.

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Infectious Pancreatic Necrosis Virus and Bacterial Kidney Disease Appearing Concurrently in Populations of *Salmo gairdneri* and *Salvelinus fontinalis*

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YAMAMOTO, T. 1975. Infectious pancreatic necrosis virus and bacterial kidney disease appearing concurrently in populations of *Salmo gairdneri* and *Salvelinus fontinalis*. J. Fish. Res. Board Can. 32: 92–95.

An investigation into disease problems at a hatchery revealed the coexistence of bacterial kidney disease and infectious pancreatic necrosis (IPN) virus in various lots of rainbow (*Salmo gairdneri*) and eastern brook (*Salvelinus fontinalis*) trout. During the study, increased mortality rates occurred in yearling brook trout with concurrent infections of bacterial kidney disease and IPN, but the mortality appeared to be primarily associated with the bacterial agent. Evidence is presented to indicate that infection with virus preceded the bacterial infection. Electron microscopic examination of kidney tissues showed that both agents could be found within the same cells.

YAMAMOTO, T. 1975. Infectious pancreatic necrosis virus and bacterial kidney disease appearing concurrently in populations of *Salmo gairdneri* and *Salvelinus fontinalis*. J. Fish. Res. Board Can. 32: 92–95.

Les recherches sur des problèmes de maladies dans un établissement de pisciculture démontrent la coexistence d'une maladie bactérienne du rein et du virus de la pancréatite infectieuse nécrosante (PIN) dans différents lots de truites arc-en-ciel (*Salmo gairdneri*) et d'ombles de fontaine (*Salvelinus fontinalis*). Au cours de l'été, il y eut augmentation des taux de mortalité d'ombles de fontaine de l'année, avec infections concommittantes par la maladie bactérienne du rein et la PIN, mais les mortalités ont semblé associées surtout à l'agent bactérien. Nous démontrons que l'infection par le virus précède l'infection bactérienne. L'examen du tissu rénal au microscope électronique indique que les deux agents peuvent se trouver dans les mêmes cellules.

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DURING the summer of 1972, a study of bacterial and viral diseases of all lots of rainbow (*Salmo gairdneri*) and brook (*Salvelinus fontinalis*) trout was conducted at the Maligne River Trout Hatchery at Jasper National Park, Alberta, Canada. This study was undertaken because of persistently high mortalities in fish over a period of years. Initial investigations showed that infectious pancreatic necrosis (IPN) was present in fish of all ages except the young fry (Yamamoto 1972 and 1974). Bacterial kidney disease as well as nephrocalcinosis was detected in a few of the brood stock and bacterial gill disease was present in certain lots of young fry (Yamamoto 1972). This report illustrates the manner in which two of these agents, IPN virus and the bacterium of bacterial kidney disease, were found to appear concurrently in populations of fish resulting in increased mortalities.

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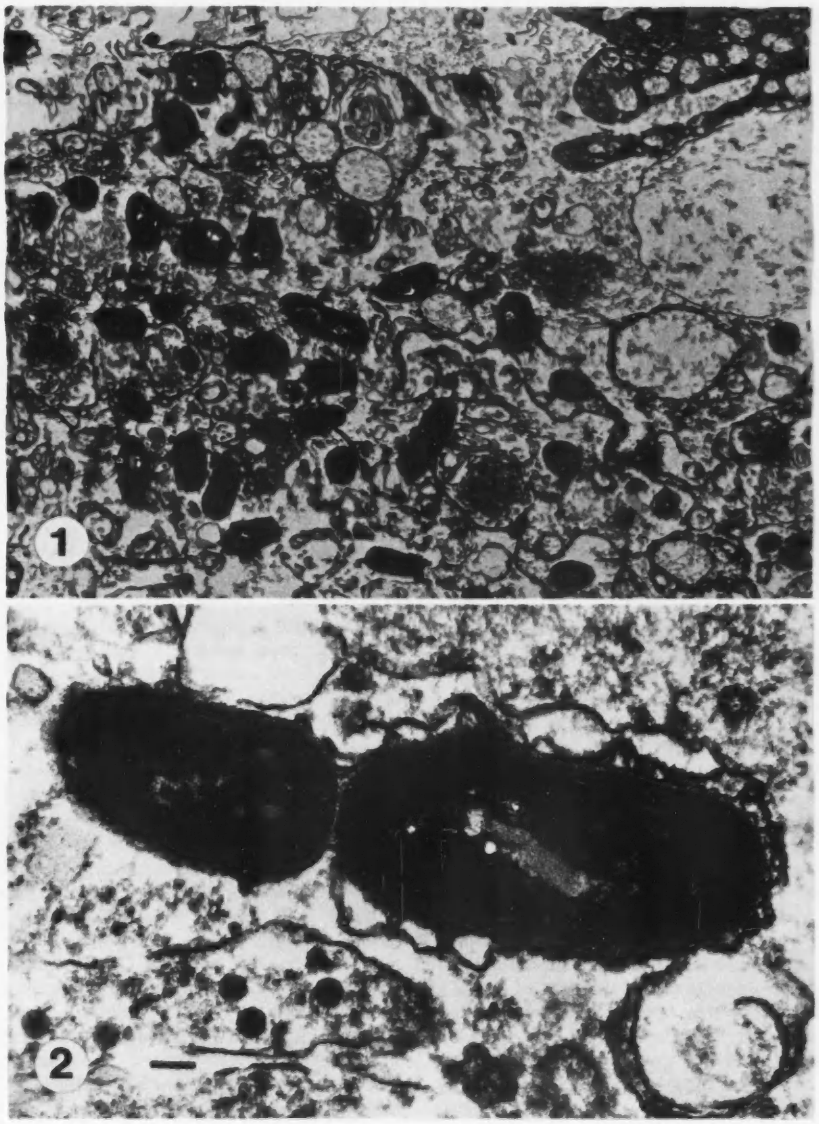
Materials and methods — The presence of IPN virus was detected by direct isolation in tube cultures of a chinook salmon embryo cell line (CHSE-214) obtained from Dr J. L. Fryer, Oregon State University, Corvallis, Oreg. The virus was identified to be IPN by morphology and seroneutralization (Yamamoto 1974). The other agent, the gram positive bacillus tentatively called *Corynebacterium* sp., that causes the disease usually referred to as bacterial kidney disease (Ordal and Earp 1956) was characterized by grossly enlarged suppurative lesions. This agent was readily detected by their presence in large numbers in impression smears. The characteristic appearance of both organisms in trout kidneys is shown in electron micrographs of thin sections (Fig. 1 and 2). Field observations showed "white boils" in various areas in the kidneys of grossly infected fish.

Results and discussion — IPN and bacterial kidney disease were detected in only a few of the rainbow trout periodically sampled from April to August (Table 1). In these lots of fish there did not appear to be a correlation of those positive



FIGURES 1 and 2

FIG. 1. Electron micrograph of a thin-section of infected kidney tissue showing many typical intracellular bacilli. (Bar indicates 1.0 μm.) FIG. 2. Thin-section of diseased kidneys showing the presence of diplobacilli and IPN particles in the same cell. (Bar indicates 0.1 μm.)
Yamamoto — J. Fish. Res. Board Can.

TABLE 1. Incidence of bacterial kidney disease and IPN virus infection in rainbow (*Salmo gairdneri*) and brook (*Salvelinus fontinalis*) trout.

Date	Age	No. of fish sampled	No. of kidneys containing bacteria	No. of animals yielding virus
Apr. 24	4 yr (Brood) R	12	0	0
	3 yr (Brood) B	11	2	11
July 6	4 yr (Brood) R	6	NE[a]	1
	3 yr (Brood) B	16	0	13
July 10	4 yr (Brood) R	10	2[b]	2
	2 yr (Brood) B	20	0	19
July 14	4 yr (Brood) R	6	0	0
	Yearling B	8	0	0
July 31	4 yr (Brood) R	20	0	0
	2 yr (Brood) B	11	0	6
Aug. 8	4 yr (Brood) R	48	2	10
Aug. 30	Yearling R	7	1	1
	Yearling B	7	6	5
Sept. 5	Yearling B	49	27[c]	47[c]

[a]Not all of the animals were examined for bacteria.
[b]NE= not examined.
[c]These numbers represent minimum values because a few animals were not examined for bacteria or for virus.

for both virus and bacteria, nor was there any apparent illness associated with these agents.

Only a few brook trout brood stock were carriers of bacterial kidney disease, but virus was isolated from most of the examined animals (Table 1). The 2-yr-old brook trout were also found to be infected with virus. In contrast, the yearling stock of brook trout appeared to be free of virus on July 14 but infection of the lot had occurred by August 30 and at which time sick fish were highly infected with the bacterial kidney disease agent. There was a marked increase in illness and mortalities in the population of yearling brook trout about this time. Therefore, on September 5 a larger sample of fish was obtained and separated into two groups — those that appeared healthy and those obviously ill and dying. The results of this sampling are in Table 2, together with some data from Table 1 listed according to the health state of the fish. There was a good correlation of illness with the presence of bacteria but not with the presence of virus. Electron micrographs of kidney sections occasionally showed both bacteria and IPN virus in the same cells (Fig. 2).

In the case of IPN disease, it is well known that salmonids when in their fry or early fingerling stage are markedly affected, but when infected after they reach yearling age or over, show no signs of disease. The findings shown in Tables 1 and 2 further substantiate the earlier reports on the increase in resistance of fish with increasing age. These observations indicate that both the bacterial kidney disease agent and IPN virus were present in older lots of fish, but that the yearling animals had become infected with both agents only during the month of August.

In the case of bacterial kidney disease, it has been shown by others (Warren 1963; Wood 1968) that infection exists with a certain level of mortalities, the severity being accentuated perhaps by other environmental factors. This study also indicates that mortalities were associated with bacterial kidney disease (Table 2) in the yearling fish, but it is difficult to assess the role played by the virus infection either in initiating bacterial kidney disease or in promoting mortalities.

The presence of bacteria and virus in the same cells of the kidney deserves comment. One explanation is that both these agents had multiplied elsewhere in the tissues and had subsequently become ingested by phagocytic cells. The other pos-

TABLE 2. Comparison of healthy and sick or moribund yearling brook trout with respect to the incidence of bacterial kidney infection and IPN virus infections.

Condition of animal	Date	Total no. of animals	No. of animals with bacteria	No. of animals yielding virus
Healthy	July 14	8	0	0
	Sept. 5	19	0	16
Sick or Moribund	Aug. 30	7	6	5
	Sept. 5	30	21[a]	26[a]

[a]These numbers represent minimum values because a few animals were not examined for bacteria or for virus.

sibility is that certain cells in the kidneys provide a suitable environment for multiplication of both agents. Because the bacteria were present in these cells, it is possible that they prefer an intracellular habitat. In the case of the virus, because relatively large numbers could be seen in and near membrane structures in the cytoplasm of kidney cells not unlike those seen in infected tissue culture cells, it is likely that replication of the virus occurs in these cells.

The results of this study indicate that the bacterial kidney disease infection was preceded by viral infection and that mortalities were primarily associated with bacterial infection. Wolf (1970) also discussed the occurrence of dual infections and the role of different agents in disease. He indicated that the immediate cause of death is not the virus which is often present in small numbers per gram of tissue as against 10^8/g in cases of cause of death of young fingerlings, but often is due to bacterial infection.

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PERSPECTIVES

Environmental Impact Assessment and Hydroelectric Projects: Hindsight and Foresight in Canada

The proceedings of a Symposium of the Canadian Conference on Freshwater Fisheries Research held at Ottawa, Ont., on January 7 and 8, 1974

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Foreword

Hydroelectric generation has historically furnished the bulk of Canada's electricity. Construction of dams began in earnest around the turn of the century and the pace has never slackened since. As late as 1950 hydro accounted for over 90% of Canada's electric generating capacity. By 1972 the growth of fossil fuel and nuclear stations had reduced this proportion to 65%, but hydroelectric capacity had mushroomed to 32,501 MW and another 23,000 MW were planned or under construction. Canada's total economically feasible hydroelectric potential is thought to be around 95,000 MW.

While famous cases such as the Bennett or Aswan dams have increased public awareness of the ecological effects of major hydro projects, few realize the extent to which they have already modified the Canadian environment. By 1970 there were 288 large hydroelectric dams in Canada and another 64 multipurpose structures. Projects larger than 100 MW alone have affected more than 50 rivers, including such major systems as the Columbia, Peace, Saskatchewan, Churchill, Nelson, St. Lawrence, Ottawa, Manicouagan, St. John, and Churchill (Labrador). Schemes have been proposed for most of the remaining large wild rivers of Canada.

Hydroelectricity is often given the misnomer "nonpolluting," and indeed it has many advantages. First, it is the only renewable source of energy now available on a large scale. Second, it has no direct effects on human health. In some cases, generation of electricity can be combined with flood control, irrigation, forest exploitation, or recreational benefits. Traditionally, it has been cheap and reliable, and it is particularly useful for meeting peak load requirements.

"Nonpolluting," however, is hardly an adequate description. Hydroelectric projects have permanent environmental impacts whose scope and diversity are sometimes hard to comprehend. These include the radical alteration of landscapes, loss of both renewable and nonrenewable resources, and the destruction of human communities and cultures.

This section contains invited papers presented at the Canadian Conference for Freshwater Fisheries Research meeting in Ottawa on January 8th, 1974. The idea of the symposium was to bring together scientists who were directly interested in environmental impact assessment of large hydrodam projects in Canada with a view to exposing their different approaches, problems, and successes. Obviously, it was not possible to invite

Avant-propos

Dans le passé, le Canada a obtenu la majeure partie de son électricité de sources hydrauliques. La construction de barrages a commencé pour de bon au tournant du siècle, et son rythme ne s'est jamais ralenti depuis. A une date aussi récente que 1950, le pouvoir hydraulique représentait plus de 90% de la capacité totale du Canada en électricité. En 1972, l'usage croissant de carburants fossiles et la prolifération d'usines nucléaires réduisirent cette proportion à 65%. La capacité hydro-électrique a quand même grimpé en flèche à 32,501 MW, alors que la production de 23,000 MW supplémentaires est en voie de planification ou de construction. On est d'avis que le potentiel hydro-électrique rentable du Canada se situe, au total, aux environs de 95,000 MW.

Des cas fameux, tels les barrages Bennett et Assouan, ont éveillé la conscience publique sur les effets écologiques de projets hydro-électriques majeurs. Par ailleurs, peu de gens réalisent jusqu'à quel point de tels projets ont déjà modifié l'environnement canadien. En 1970, on comptait au Canada 288 grands barrages et, en plus, 64 structures polyvalentes. Les projets dépassant 100 MW affectent à eux seuls plus de cinquante fleuves et rivières, y compris les réseaux majeurs suivants: Columbia, de la Paix, Saskatchewan, Churchill, Nelson, Saint-Laurent, des Outaouais, Manicouagan, Saint-Jean et Churchill (Labrador). On a déjà soumis des plans pour la plupart des autres grands cours d'eau sauvages canadiens.

On désigne souvent à tort l'hydro-électricité comme un « non-polluant », et elle a de fait plusieurs avantages. En premier lieu, elle est la seule source d'énergie renouvelable à notre disposition sur une grande échelle. En second lieu, elle n'a pas d'effet direct sur la santé humaine. Dans certaines cas, la production d'électricité peut être combinée avec le contrôle des inondations, l'irrigation, l'exploitation forestière ou les installations récréatives. Elle est par tradition peu coûteuse et fiable, et se prête particulièrement bien aux exigences des périodes de pointe.

« Non-polluant », cependant, n'est pas un qualificatif tout à fait adéquat. Les projets hydro-électriques ont des impacts environnementaux permanents dont l'étendue et la diversité sont parfois difficiles à saisir. On peut citer, entre autres, la transformation radicale des paysages, la perte des ressources, tant renouvelables que non renouvelables, et la destruction des communautés et des cultures humaines.

Ce numéro contient des articles présentés sur invitation à la Conférence canadienne relative à

someone from every project in Canada but a wide coverage of regional reservoir-type was attempted (Fig. 1).

Whilst organizing the symposium it became clear that most people had little idea of the number and size of our power dams and reservoirs and that the data were not readily available. With the help of T. L. Perry Jr., I have prepared a list of projects over 100 MW in size as an appendix. There has been a tendency to ignore what the past can teach us when assessing the impact of a new dam and reservoir. I am sure that better understanding of the impact of future dams could be obtained by examining the wide range of size and age of some of the 365 dams listed in the appendix.

The present approach to environmental impact assessment is somewhat haphazard. There is a tendency to gather data, based on the old limnological and ecological techniques, without systematically defining the questions being asked and the relevance of the data to the answers. If I can choose one paper for special attention it is the one on the James Bay Development by A. F. Penn. This is written for the biologist from the perspective of the customer. The lawyer actually uses the environmental assessment results in court or before a tribunal. It is obvious that to date

la recherche sur les pêches en eau douce, tenue à Ottawa le 8 janvier 1974. Le but du colloque était de réunir les scientifiques directement intéressés à l'évaluation de l'impact environnemental des grands barrages hydro-électriques au Canada, et de les entendre exposer leurs différentes méthodes d'attaque, leurs problèmes et leurs succès. Il a été évidemment impossible d'inviter un représentant de chaque projet canadien, mais on s'est efforcé de couvrir, sur base régionale, le plus de réservoirs possibles (Fig. 1).

Lors de l'organisation du colloque, on s'est vite rendu compte que la plupart des gens n'avaient qu'une faible idée du nombre et de la taille de nos barrages et réservoirs hydro-électriques, et que les données étaient difficilement accessibles. Avec l'aide de T. L. Perry jr, j'ai préparé en appendice une liste des projets de plus de 100 MW. En évaluant l'impact d'un barrage et d'un réservoir nouveaux, on a eu tendance à ignorer les leçons du passé. Je suis sûr qu'on comprendra mieux l'impact des barrages futurs, si l'on considère la gamme étendue de tailles et d'âges de quelques-uns des 365 barrages énumérés en appendice.

L'évaluation de l'impact environnemental se fait présentement un peu au petit bonheur. On a tendance à recueillir des données, selon les an-

Canadian biologists have been unable to provide the customer with an adequate product. We are still groping in the dark and feeling for the method of approach and the type of answers which are both biologically accurate and legally acceptable. Maybe the answer is a new profession of environmental impact consultants who will use sophisticated modeling to define the magnitude of the problem clearly. It may also require a new profession of environmental lawyers, and even judges, who can define the question better and understand the answers.

These papers attempt to show that we have a long way to go before we reach an acceptable level of sophistication in the field of environmental impact assessment in Canada.

I. E. EFFORD

ciennes techniques limnologiques et écologiques, sans définir de façon systématique les questions qui se posent et l'applicabilité des données aux réponses. Qu'il me soit permis de choisir un article en particulier, celui d'A. F. Penn sur le développement de la baie James. Cet article a été rédigé pour le biologiste, du point de vue du client. En fait, l'avocat se sert des résultats de l'évaluation environnementale à la cour ou devant un tribunal. Il est évident que les biologistes canadiens n'ont pu, jusqu'à maintenant, fournir au client un produit adéquat. On cherche encore à l'aveuglette et par tâtonnements la méthode d'attaque et le type de réponses à la fois biologiquement précis et légalement acceptables. La réponse se trouve peut-être dans une nouvelle profession, celle de consultant en impact environnemental, qui fera appel à des modèles raffinés pour définir clairement l'envergure du problème. Il se peut qu'on ait également besoin d'une autre profession nouvelle, celle d'avocats et même de juges versés dans les questions d'environnement, qui seraient à même de mieux définir les questions et comprendre les réponses.

Les articles qui suivent veulent démontrer qu'il y a encore beaucoup à faire pour atteindre un niveau de raffinement acceptable dans le domaine de l'évaluation de l'impact environnemental au Canada.

I. E. EFFORD

Impact Analysis: Hindsight and Foresight in Saskatchewan[1]

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ATTON, F. M. 1975. Impact analysis: hindsight and foresight in Saskatchewan. J. Fish. Res. Board Can. 32: 101–105.

Three hydro-developments in Saskatchewan are described. A fourth reservoir proposal is under study and is to be reviewed for a decision in 1975. This appears to be the first project where impact analysis is being carried out before implementation is decided upon. A brief résumé of information on these impoundments includes limnology, aquatic ecology, and water quality. This enables us to describe the impact of impoundment and inundation more broadly than consideration of the fishery resource only. Particular attention is given to the need for shoreline mapping, terrain description, forest clearing, erosion prediction, permafrost discovery, and mitigation of effects on fishery resources. The discussion emphasizes the practical approach.

ATTON, F. M. 1975. Impact analysis: hindsight and foresight in Saskatchewan. J. Fish. Res. Board Can. 32: 101–105.

Nous décrivons trois développements hydro-électriques en Saskatchewan. Le projet d'un quatrième réservoir est à l'étude et sera examiné en vue d'une décision en 1975. Il semble que ce soit le premier projet pour lequel une étude d'impact a été effectuée avant de décider de son exécution. Un bref résumé de nos connaissances sur ces endiguements porte sur la limnologie, l'écologie aquatique et la qualité de l'eau. Ceci nous permet de décrire l'impact de l'endiguement et de l'inondation en termes plus étendus qu'une considération de la ressource halieutique seulement. Nous soulignons de façon particulière le besoin de cartographie de la ligne de rivage, description du terrain, déforestation, prévision d'érosion, découverte du pergélisol et atténuation des effets sur les ressources halieutiques. La discussion fait ressortir la méthode d'attaque pratique.

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ENVIRONMENTAL assessment is not a new activity for ecologists, though in the past it may have been less inclusive than the term now implies. Aquatic studies have frequently had a broad base of inventory, analysis, and prediction, especially when concerned with productivity and other fishery management problems. As a result ecologists are not entirely without experience, philosophy, or techniques to undertake what may seem to be a new area and responsibility.

The new character of the work arises in two aspects. The first is the emphasis on impact — this now adds to the assessment a particular disturbance to be taken into account. The second aspect is the applied nature of the work, which imposes usually rather stringent time limits. Research and management ecologists have tended to plan programs in an open-ended way, from several years to a decade or more in duration. Environmental impact assessment obviously requires a more business-like (consultant) approach, with prior commitments concerning scope and time for the work.

The purpose of this paper is to examine the hydroelectric projects which have been carried out in Saskatchewan and to determine the scope needed for feasible impact assessment.

Saskatchewan has six reservoirs all related to electric production. On three of these we have little or no information. Tazin Lake (1939) is a small project in the northwest of the province (Fig. 1) which supplies power to the uranium mines north of Lake Athabasca and to the town of Uranium City. Boundary Reservoir in the southeast was built in 1959 to provide cooling water for the coal-burning thermal power station on its shore. Island Falls reservoir on the Churchill River is the oldest hydroelectric power development in the province. It was built in 1929 by the Churchill River Power Company to provide electric power for Flin Flon, Manitoba, and the mines associated with that town.

The three remaining reservoirs are Reindeer, Tobin, and Diefenbaker. We also have a proposal for a hydroelectric power reservoir on the

[1]Prepared for the Canadian Conference on Freshwater Fisheries Research held at Ottawa, Ont., on January 7–8, 1974.

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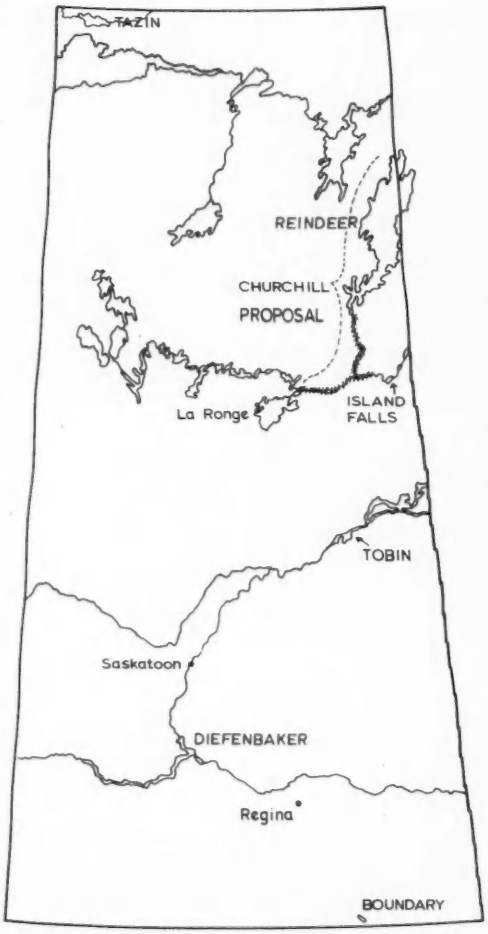

FIG. 1. Location of six Saskatchewan reservoirs.

Churchill River, which is now the subject of an impact assessment study. I believe that this impact study is the first instance in Canada where (a) the impact assessment will be completed before the government decides to permit development, and (b) the policy is to maintain completely open information about this study as it proceeds. I will examine these four projects to see if there is some profit in hindsight and foresight.

Reservoir Characteristics

Several classes of information are used in impact studies. The locations of these reservoirs appear in Fig. 1 and their general characteristics are shown in Table 1. Reindeer Lake was raised a total of 2 m between 1937 and 1942. This impoundment was entirely for water storage for the downstream Island Falls power plant. The recorded low water level for Reindeer Lake occurred on April 4, 1929, 2.8 m below the present full supply level. The greatest drawdown was in 1971 and amounted to 2.3 m. It is my opinion that much can be learned from Reindeer Lake, as a reservoir, because 1) the reservoir is now 30 yr old; 2) it is a Precambrian site, of interest to the evaluation of the Churchill proposal, and other northern projects; 3) we have considerable background information.

The south end area of the lake was examined by a biologist in 1946. D. S. Rawson, with an assistant, spent 3 wk on the lake in 1951, and N. S. Novakowski devoted a summer's effort to the limnology and fish populations of Reindeer Lake in 1954. The history as an impoundment has prompted us to do special work on Reindeer Lake in the present Churchill River impact study. From the staff of the Freshwater Institute at Winnipeg, Dr K. Patalas is carrying out studies on the zooplankton and Dr R. Heckie has studies in progress on the sediments of this reservoir.

Tobin Lake is on the Saskatchewan River system and is notable first because it is quite shallow and, therefore, has a rapid water exchange. A large area on the southeast of this reservoir is not more than 4 m deep. Tobin, like Reindeer, has a massive deadfall log problem because only a small part of the timber was cleared from the basin before the reservoir was filled. Tobin operates on a run-of-the-river regime, controlled mainly by discharge from Diefenbaker. Both Tobin and Diefenbaker reservoirs are designed to yield about the same number of kilowatt hours per year.

Diefenbaker Lake is almost as long as Reindeer and is a storage reservoir filled in spring and early summer. It has a very substantial drawdown and an outlet in the hypolimnion. The basin of this reservoir contained some agricultural land, a large amount of prairie, and some light scrub areas in the ravines and draws of the river valley. As a result, though there was not extensive clearing, there is only a limited occurrence of debris.

The Churchill proposal will be seen to have the following major characteristics: site — Precambrian, resembling Reindeer; drawdown — resembling Reindeer; inundation — approximating Tobin; depth — resembling Diefenbaker; outlet — epilimnial–metalimnial.

The second component needed for impact assessment is a description of the biological con-

TABLE 1. Characteristics of three Saskatchewan Reservoirs and a proposed impoundment.

	Reindeer	Tobin	Diefenbaker	Churchill
Location	N.E. Sask.	Sask. R.	S. Sask. R.	Churchill R.
Site	Precam. lake	Sedimentary	Sedimentary	Precam. lake
Construction	1937	1960	1959	
Filled	1942	1963	1967	
Area (km^2)	5,576	228	477	900
Length (km)	232	74	222	114
Depth (m) max.	219.5	26.4	59.0	54
mean	17?	8.0	20.0	
Volume ($m^3.10^6$)	105,000	1,935	9,534	
Shoreline (km)	4,345	158	1,091	
Inundation (m)	2.0	24.4	57.9	29.2
Drawdown (m)	2.3	1.3	10.6	3.7
% volume		12	25	
Outlet (m) FSL	0	0	34	10
	Epilimnial	Epilimnial	Hypolimnial	Metalimnial
Power (kwh/yr)	Storage	1×10^9	1.1×10^9	1.5×10^9
Consumers	Man.	Sask.	Sask.	
Diversion (m^3/s)	–	–	11 Qu'Appelle	–

ditions, whether before or after the impoundment. For the three reservoirs we are examining, we have the information shown in Table 2, obtained after the filling of the reservoirs. These studies provide much of the physical–chemical description needed and some at least of the biological information will be useful.

A third important category of information provides for a broad perspective on the aquatic impact of the proposed hydro-dam. For the Churchill River Study in Saskatchewan we have the study sectors shown in Fig. 2, with the exception of the legal component. In my view, we deal with three major levels of impact as shown on the left column of the figure. Dr W. Kupsch, our study director, has pointed out that this program is in fact ". . . a planning exercise in land use."

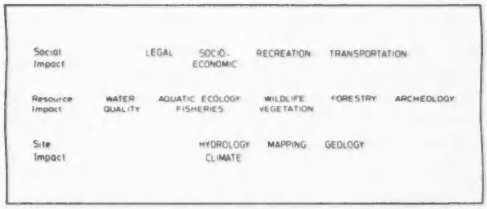

FIG. 2. Study sectors for the Churchill River Study.

TABLE 2. Components of the limnobiological studies available for three reservoirs in Saskatchewan.

Limnology:	
Morphometry	– area, depth, volume, water exchange, drainage basin, shoreline
Physics	– temp., Secchi disc
Chemistry	– O_2, pH, alkalinity, hardness, TDS, water analysis
Flora and fauna	– species when possible
Standing crops:	
Plankton	– composition, enumeration, weight
Benthos	– composition, enumeration, weight
Fish	– species, growth, abundance, weight, seasonal habitats, movements
Ecological analysis	– trophic status, food chains, associations, "productivity", recommended yield.

There are limitations on this description of reservoir characteristics, physical parameters, and biological components. First, some of the quantitative answers are relative. Numbers of this kind permit deduction only of some comparative results. I hasten to note, however, that absolute numbers may be even less useful. For example, estimates of the absolute number of fish in a population may engender confidence, but for those who know how these populations may fluctuate in numbers over a few years, this statistical confidence is not very reassuring. The assumption that such estimates are made when the fish populations represent peak productivity could be verified only by repeating the work for a number of years. A second limitation is that even preliminary engineering design information on the proposal is usually lacking. This is a serious limitation. There is every reason to believe that almost

all the information necessary is known, but confidentiality is a major characteristic of engineers, company executives, and midlevel government administrators.

Third, the shortfall in information from the sources described above is varied. Some may consider the following topics not the realm of limnology, aquatic ecology, and fisheries, but there are relationships to be considered. These topics are only illustrative:

1. *Shoreline mapping* — In a given terrain there is a need to develop some concept of the various components of the shoreline as rock, gravel beaches, boulder beaches, sand beaches, organic deposits, clay, silt, and finally muskeg areas. The shoreline mapping also includes similar analysis of the underwater deposits to about 1 m deep, as well as the mapping of the occurrence and distribution of aquatic plants. This information is essential for estimation of the spawning habitats available to the various species of fish that are important. An analysis of the components of the shoreline will assist greatly in describing the shoreline of the new water body, when combined with the next topic.

2. *Terrain description* — This is done mainly by geologists from aerial photos. Not only does this description provide information on the new shoreline, but also on the basin that will be flooded and will begin to contribute dissolved material to the new water body.

3. *Erosion prediction* — This of course is also related to terrain description, but may be particularly important to the aquatic ecologist in a sedimentary basin, as Diefenbaker Lake, where turbidity has been noticeable in some areas.

4. *Muskeg water quality and the discovery of permafrost* — This point is peculiar to a more northern reservoir. Even to the south of the Churchill River we have areas of permafrost in Saskatchewan, usually under wet muskeg cover and where 10–17-m forest provides considerable shade.

5. *Forest drowning* — The location, amount, and kind of forest to be inundated is important to fishing, water quality, and recreation.

6. *Mitigation of fishery damage* — This refers especially to spawning habitat and shoreline development, as well as the need for forest clearing. If these areas involve clay, extensive and continuing turbidity may result.

7. *Sediment studies* — Microfossils; sediment oxygen demand; geochemistry.

Discussion

Hindsight on these three reservoirs may identify some of the major aquatic problems induced by their creation:

Environmental problem:	Reindeer	Tobin	Diefenbaker	Cause
Littoral exposure benthos	X		X	drawdown
Spawning site freezing	X		X	drawdown
Downstream temperature			X	outlet location
Fish kills		X		outlet design
Debris	X	X		forest drowning
Stumps, deadheads	X			forest drowning
Erosion, turbidity			X	wave action
Water quality changes (spawning sites)	X			muskeg drowning
Management problem:				
Population explosions:				
Fish		X	X	new habitat
Benthos		X	X	organic bottom
Plankton	X	X	X	added nutrient

In the Churchill proposal turbidity may be a problem if there is permafrost in areas composed of fine materials. Floating muskeg may be a problem where permafrost is under this vegetation. We should note too, that these problems may have very different time frames. Some problems are reduced with time, as erosion. Some problems are long-term, perhaps 100–200 yr, as the debris from forest drowning. The littoral exposure problem will of course remain until water management regimes are changed.

Resource management problems should also be recognized. These seem to be much more complex than we generally realize, usually related to population explosion. I have seen these explosions in numbers and growth of organisms for fish, for benthos, and for zooplankton in new impoundments.

In considering the main points necessary in the preparation of an impact analysis, certain guidelines should be recognized. These are simply that the work should be realistic, useful, and comparative. Realistic means within the limits of time, staff, and cost. To be useful, the work must provide answers, not necessarily absolute, to realistic problems. These projects should seldom be the occasion for basic research. Comparative methods and procedures should allow the possibility of learning from previous work, as well as doing follow-up work. The objectives of the studies done must provide for:

i) Perspective — conscious of other disciplines and the relationships they imply.

ii) Inventory — baseline environmental description, both physical and biological, as quantitative as possible. This work must be more than traditional; it must be imaginative enough to enable impact analysis.

iii) Prediction — for each alternative proposal the identification of problems and the input data required to correct these problems.

iv) Mitigation — aquatic management concerns related to exploitation — fish, wild rice, brine shrimp, recreation; reclamation — pollution control and prevention; annihilation — ecological resources, as rare species; litigation — the area of social impact, especially the legal area.

At the risk of being monotonous, for the aquatic environment, the following list may be the minimum components for the impact assessment inventory:

Paleolimnology
- Fossil diatoms
- Insect microfossils

Bacteriology
- Standard plate count
- Coliform count
- Fecal coli count
- BOD

Physical–chemical limnology
- Bathymetry
- Hydrology
- Temperature
- Secchi disc
- O_2, pH
- Water analysis, nutrient loading

Plankton
- Species composition
- Primary productivity
- Phytoplankton—standing crop
- Zooplankton—standing crop

Aquatic plants (higher)

Benthos
- Faunal composition
- Standing crop(s)

Fish (higher vertebrates)
- Faunal composition
- Standing crop(s)

Sediments
- Sediment oxygen demand—SOD
- Physical composition—grain size
- Chemical analysis—geochemistry

Drainage Basin
- Terrain analysis — lithic, organic, topographic
- Shoreline analysis — beach and littoral
- Flooding and drowning — areas; amounts of forest, etc.

The approach is intended to be practical: species composition of plankton, for instance, should not consume 20% of the effort expended on the impact study. Practical considerations forbid extending this list too far, though two certainties seem clear; there are likely omissions, and most readers will find some favorite "essential" that has been disregarded. The list is offered as a starting place, with the question for each item — Do these data contribute to the objectives of the study? In particular, will this parameter contribute to impact assessment now and in the future?

In conclusion the environmental impact assessment, to be justified, must be an environmental feasibility study initiated parallel to the usual project feasibility study. For an effective and accurate impact assessment, all the detailed data of the project feasibility study and development must be available to the environmental study. This implies that the environmental impact assessment requires more time than the usual feasibility studies carried out by the proponents of a project.

Acknowledgments

D. L. MacLeod, Saskatchewan Environment Hydrology Branch, provided some of the information used in Table 1. Discussion with my associates in the Saskatchewan Fisheries Laboratory and with W. O. Kupsch, Churchill River Basin Study, has been very helpful.

Hydroelectric Development of the Nelson River System in Northern Manitoba[1]

I. W. DICKSON

Lake Winnipeg, Churchill, and Nelson Rivers Study, Winnipeg, Man. R3M 2K2

DICKSON, I. W. 1975. Hydroelectric development of the Nelson River system in northern Manitoba. J. Fish. Res. Board Can. 32: 106–116.

Manitoba hydro plans to divert the Churchill River at Southern Indian Lake to the Nelson River via the Rat–Burntwood rivers. Combined flows of the Churchill and Nelson rivers would generate more than 7 million kw at 14 power generating sites along the Nelson River system. Regulation of Lake Winnipeg is required to provide additional storage to augment flows in the Nelson River.

Impacts to beaches and marshes and related implications to recreation and wildlife uses are important aspects of Lake Winnipeg regulation. Long-term ecological changes to Lake Winnipeg may be significant. The level and flow pattern of other waters at the outlet from Lake Winnipeg (Outlet Lakes) will also be altered by regulation. Environmental impacts attributed to this altered regime of level and flow are likely to be of lesser significance than impacts in other areas. Life styles and cultural values of residents in the remote Cross Lake community may be affected by the project.

Diversion of 30,000 cfs from the Churchill to the Nelson River may reduce flows which have historically ranged from 20,500 cfs to 92,000 cfs (mean of 34,000 cfs) to minimum winter and summer flows of 1,500 and 500 cfs, respectively. While socioeconomic considerations and related resource implications appear to be of relative minor importance, altered levels, flows, and associated ice regime may be expected to significantly alter the aesthetic qualities of the river. Raising Southern Indian Lake level may cause major changes to the appearance of the landscape and the utilization of associated resources. Socioeconomic implications of flooding may be significant.

Storage and release of waters from impoundments along the Rat–Burntwood diversion route will significantly alter the characteristics of the land–water interface. Flows increased from 4,000 to 34,000 cfs and flooding will have a major impact on availability and utilization of associated resources. Notigi Lake control for Churchill River diversion will cause flooding of about 40,500 hectares or approximately 158 square miles. Additional flooding of approximately the same area below the Notigi Control can be anticipated following diversion and the development of Wuskwatim and Manasan sites on the Burntwood River.

DICKSON, I. W. 1975. Hydroelectric development of the Nelson River system in northern Manitoba. J. Fish. Res. Board Can. 32: 106–116.

L'Hydro-Manitoba se propose de dériver la rivière Churchill au lac sud des Indiens vers le fleuve Nelson, via les rivières Rat–Burntwood. Le débit combiné de la rivière Churchill et du fleuve Nelson produiront plus de 7 millions kw à 14 stations hydro-électriques sur le réseau du fleuve Nelson. Il faudra régulariser le lac Winnipeg, en vue d'un emmagasinement supplémentaire qui augmentera les débits dans le fleuve Nelson.

L'impact sur les plages et les marécages et, par association, sur la récréation et le gibier, sont des aspects importants de la régularisation du lac Winnipeg. Il se peut que les modifications à long terme du lac Winnipeg soient importantes. Le niveau et le débit des autres masses d'eau à la sortie du lac Winnipeg (Outlet Lakes) seront également affectés par la régularisation. L'impact sur l'environnement attribuable à ces changements de niveau et de débit sera probablement moins important que dans d'autres régions. Il se peut que le mode de vie et les valeurs culturelles des résidents de l'agglomération rurale éloignée de Cross Lake soient affectés par le projet.

La dérivation de 30,000 pi^3/sec de la rivière Churchill vers le fleuve Nelson peut réduire les débits qui, traditionnellement, ont varié de 20,500 à 92,000 pi^3/sec (moyenne de 34,000 pi^3/sec) et de minimum d'hiver et d'été de 1,500 et 500 pi^3/sec respectivement. Bien que les considérations socioéconomiques et autres implications de la ressource qui s'y rattachent semblent avoir une importance relativement mineure, des changements de niveau, de débit et de régime de glaces qui

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s'ensuivront affecteront probablement les qualités esthétiques de la rivière. Une élévation du niveau du lac sud des Indiens peut entraîner des changements majeurs dans l'aspect du paysage et l'utilisation des ressources qui s'y rapportent. Il se peut que l'endiguement ait d'importantes implications socioéconomiques.

L'emmagasinement et la décharge des eaux de retenue le long de la voie de dérivation Rat–Burntwood affecteront de façon significative les caractéristiques de la surface séparant la terre et l'eau. Des débits qui passeront de 4,000 à 34,000 pi³/sec et la submersion auront un impact majeur sur l'accessibilité et l'utilisation des ressources. La régularisation du lac Notigi associée à la dérivation de la rivière Churchill inondera environ 40,500 hectares ou 158 milles carrés. On peut s'attendre qu'une superficie supplémentaire à peu près semblable sera inondée en aval du lac Notigi à la suite de la dérivation et du développement aux sites Wuskouatim et Manasan, sur la rivière Burntwood.

Accepted September 9, 1974 Accepté le 9 septembre 1974

THE purpose of this paper is to describe briefly the scope of the proposed Nelson River hydroelectric development, to outline those aspects of the development under study by the Lake Winnipeg, Churchill, and Nelson Rivers Study, and to discuss, generally, the nature of anticipated physical, biological, economic, and social impacts and associated studies.

Manitoba Hydro has developed plans for a multibillion dollar development of the hydroelectric potential of the Churchill and Nelson rivers in northern Manitoba which would increase Canada's present installed power production capacity by about 15%. The power production capacity of the proposed Nelson River hydroelectric development is generally of the same order of magnitude as the La Grande hydroelectric development proposed for the James Bay area, Quebec and the recently completed Churchill Falls hydroelectric development, Labrador. The completed development would constitute 14 power generating stations capable of producing more than 7 million kw (Fig. 1). One of the fourteen generating stations (Kelsey) was completed in 1960. A second generating station, at Kettle Rapids, is nearing completion, and generating stations at Jenpeg and Long Spruce are currently under construction.

Although the hydroelectric potential of the Churchill and Nelson rivers has been recognized by Manitoba Hydro and the Manitoba government since the turn of the century, more economical and accessible power sources in southern Manitoba were given priority. The Winnipeg River hydroelectric development satisfied much of the major power requirements in Manitoba prior to and during the early 1950s.

Increasing demands for electrical energy generally, and in particular a new power supply required for the development of a mining/smelting operation by the International Nickel Company of Canada at Thompson, focused attention on the hydroelectric potential of northern Manitoba rivers. The Kelsey generating station on the lower Nelson River some 500 miles north of Winnipeg was completed by Manitoba Hydro to meet the power requirements for the new industrial development at Thompson. In 1961 Manitoba Hydro began building the Grand Rapids generating station on the Saskatchewan River approximately 250 miles north of Winnipeg. Development of the hydroelectric potential of northern Manitoba rivers had begun!

In 1963 and 1964, Canada and Manitoba entered into agreements for joint studies of a development program for the power potential of the Nelson River. Based on recommendations from these studies, Canada and Manitoba signed an agreement in 1966 to proceed with hydroelectric development of the Nelson River.

To develop the hydroelectric potential of the Nelson River, Manitoba Hydro proposed to divert a major portion of the Churchill River through generating stations situated along the Nelson River system. (The Nelson River system includes the portion of the Nelson River drainage from Lake Winnipeg to Hudson Bay.) Although the Churchill River is suited for hydroelectric development, its location some 100 miles north of the Nelson and the associated increase in costs of development and transmission precluded its development. Diversion of the Churchill River through generating stations along the Nelson River system as opposed to the development of sites on the Churchill River has been estimated to represent economic benefits of some $400 million.

A plan advanced by Manitoba Hydro in 1968 for hydroelectric development of the Nelson River system proposed raising waters of the Churchill River at Southern Indian Lake (a widening of the Churchill River) by approximately 35 ft, and diverting these waters into the Nelson River system via the Rat and Burntwood rivers to the Nelson. However, in 1970 the Manitoba govern-

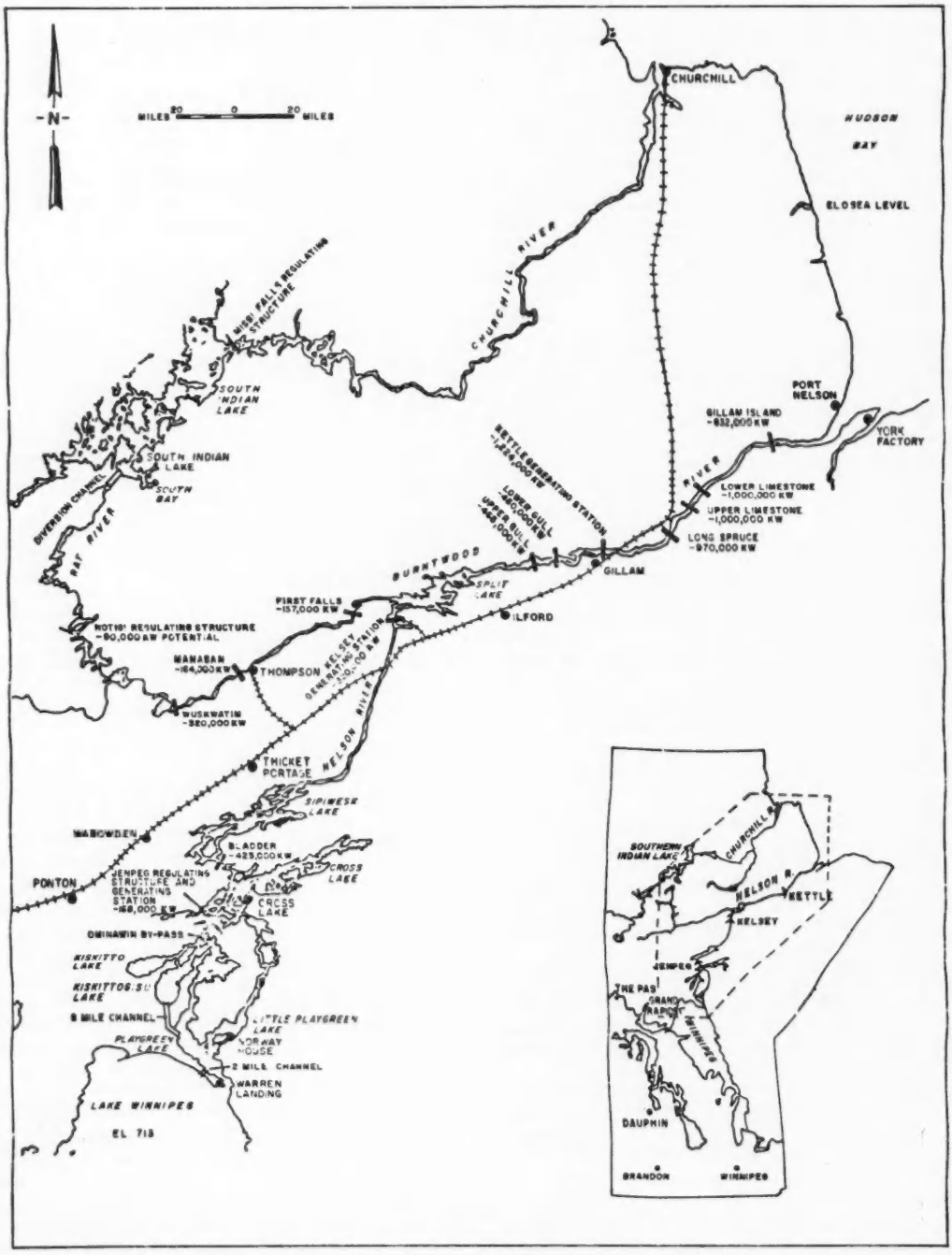

FIG. 1. Hydroelectric development of the Nelson River system in northern Manitoba.

ment deemed this "high-level" diversion plan socially unacceptable because of concern for the social impact of relocation of the South Indian Lake community, and associated environmental consequences.

An alternative "midlevel" development plan was proposed by Manitoba Hydro in 1970 whereby the Churchill River would be diverted by raising Southern Indian Lake levels about 10 ft from the present lake level, not to exceed a maximum elevation of 850 ft. Additional storage required for the increased generating capacity on the lower Nelson River would be provided by the regulation of Lake Winnipeg.

The Manitoba government granted Manitoba Hydro an interim license to proceed with Lake Winnipeg regulation in November, 1970.

In September, 1971 a Canada–Manitoba Study Agreement was signed authorizing studies of the effects of Lake Winnipeg regulation, Churchill River diversion, and development of hydroelectric potential of the Churchill River diversion route on other water and related resource uses. The Lake Winnipeg, Churchill, and Nelson Rivers Study (hereinafter referred to as the Study) is to recommend means by which to enhance overall benefits, with due consideration for protection of the environment.

In December, 1972 Manitoba Hydro received authority from the Manitoba government to proceed with the Churchill River diversion. Construction of the various regulatory and control works required for Lake Winnipeg regulation and Churchill River diversion is proceeding.

Nelson River Hydroelectric Development

Manitoba Hydro's proposed sequence for power development involves, respectively, Lake Winnipeg regulation and Churchill River diversion from Southern Indian Lake to the Nelson River. Lake Winnipeg will be regulated by an improved outlet capacity at the north end of the lake and a control and power generating facility on the West Channel of the Nelson River (Fig. 2).

The Churchill River will be diverted by a control dam at Missi Falls at the outlet of Southern Indian Lake. Water will be diverted from South Bay at Southern Indian Lake through a diversion channel to Issett Lake, the headwaters of the Rat River. A control structure at the outlet of Notigi Lake on the Rat River will regulate the release of water down the Burntwood River and thence to the Nelson River (Fig. 3).

Hydroelectric power will be produced from numerous generating stations situated along the Rat–Burntwood diversion route and the Nelson River (Fig. 1).

Lake Winnipeg Regulation

Lake Winnipeg is the largest Manitoba lake, having a surface area of 9430 square miles. It ranks as the twelfth largest lake in the world, draining a 380,000-square mile watershed extending to the Canadian Rockies. Waters flow out of the north end of Lake Winnipeg to the Nelson River via the West and East channels. The major portion of the flow from Lake Winnipeg moves through the West Channel via Playgreen Lake and Kisipachewuk, Metchanais, and Ominawin rapids to Cross Lake. The remainder of the Nelson River flow enters Cross Lake via Little Playgreen Lake and the East Channel.

Lake Winnipeg is particularly suited for hydroelectric purposes because of its large storage. By increasing the outlet capacity and regulating flows from Lake Winnipeg, winter flows in the Nelson River required for power generation can be increased to coincide with peak annual energy demands. Flood control benefits for lands bordering the lake may also accrue to the project.[2]

In order that waters may be stored and released for power generation, Lake Winnipeg will be regulated between 711 and 715 ft by a control dam and generating facility on the West Channel of the Nelson River and by-pass channels at the north end of the lake. Further, a lesser system of dams and dykes will be constructed in the project area to increase hydraulic control and restrict flooding (Fig. 2).

West Channel control and generating facilities — The regulating structure and generating station constructed at Jenpeg on the West Channel of the Nelson River (Fig. 2) will control approximately 80% of the average Lake Winnipeg outflow (70,000 cfs). The Jenpeg generating station will generate 168,000 kw by using a head of approximately 25 ft, creating an impoundment of an undetermined surface area but relatively restricted to the immediate area of the West Channel. Average annual flows through the six turbines at Jenpeg will be slightly less than the average unregulated flows in this part of the West Channel. A clearing program to partially clear the Jenpeg forebay area has begun and will be completed before impoundment begins in 1974. Dyk-

[2]"Project" is used throughout the text of this paper when referring to any portion of the proposed Nelson River hydroelectric development.

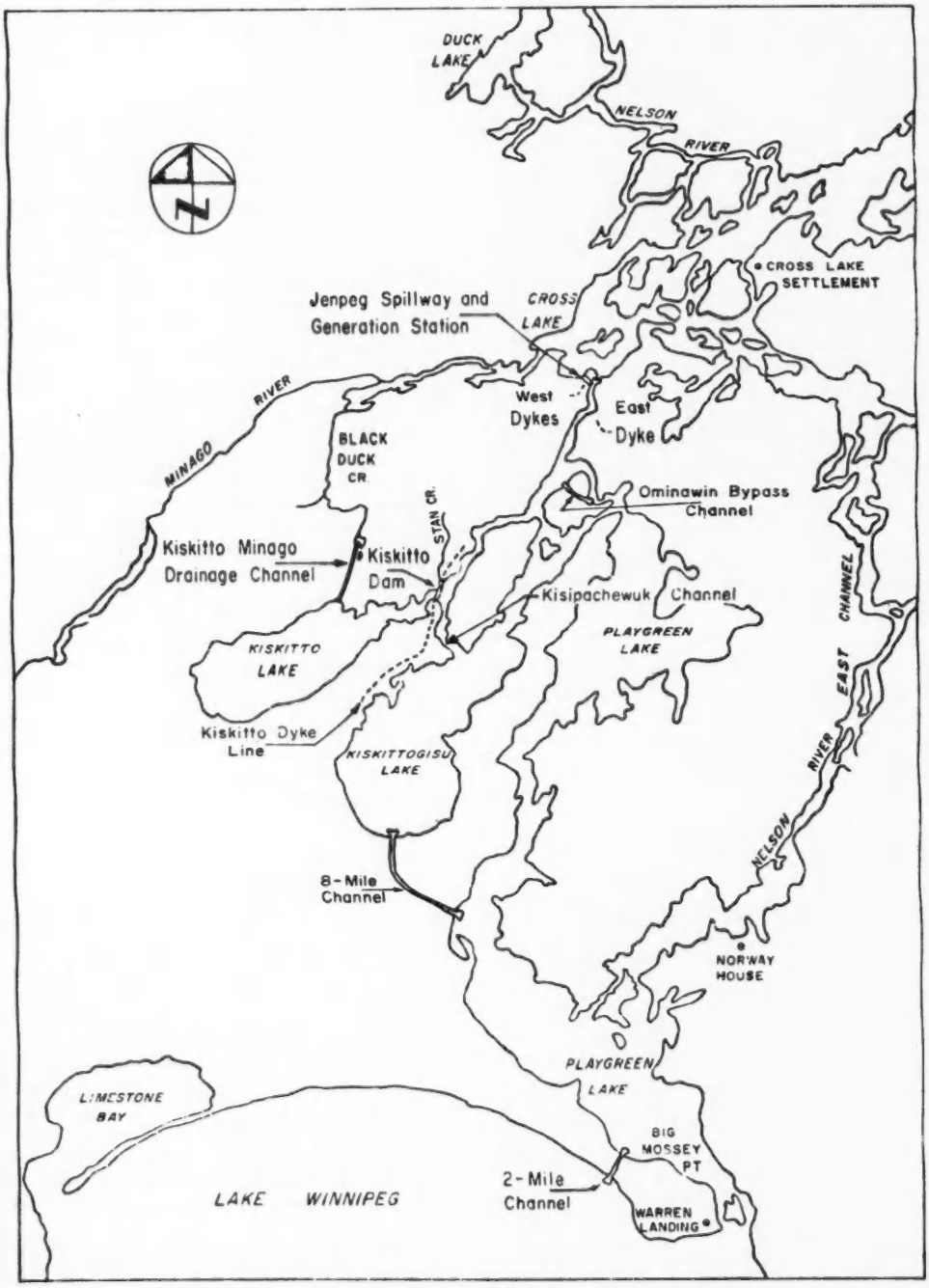

FIG. 2. Lake Winnipeg regulation scheme.

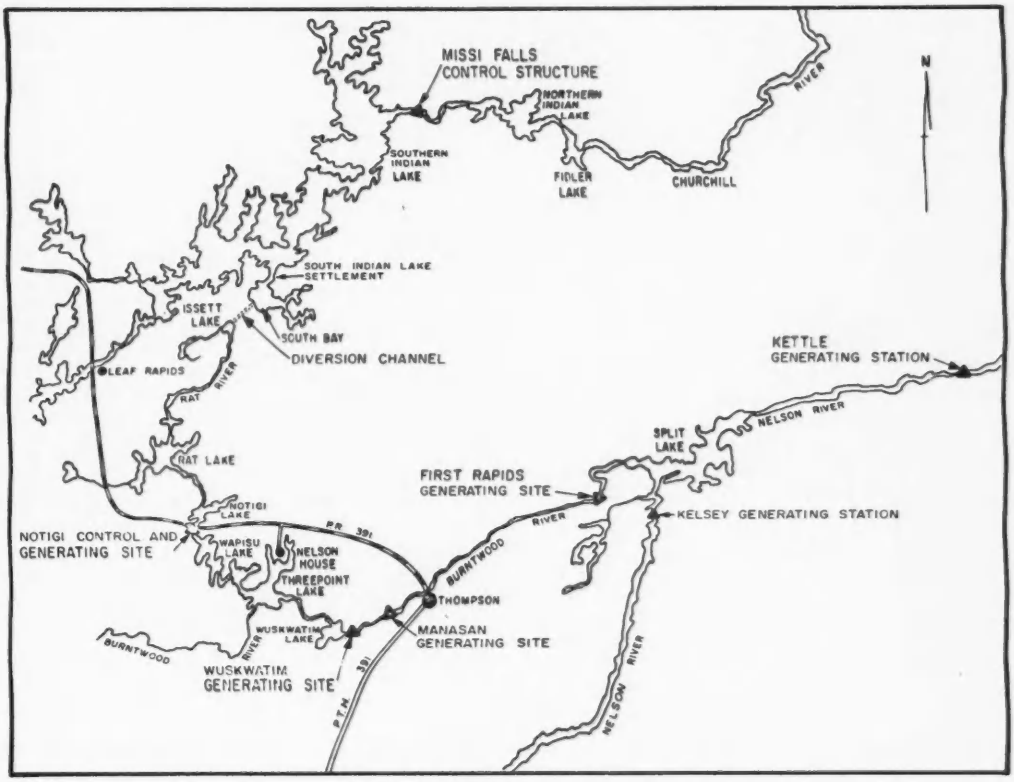

FIG. 3. Churchill River diversion scheme.

ing has been designed to restrict flooding in some areas as a result of increased water levels in the West Channel. Power production at this site is expected for 1976.

Outlet channels — Three channels referred to as Eight-Mile Channel, Two-Mile Channel, and Ominawin By-pass are being excavated to increase the outflow capacity of the lake. Limited channel improvement has been completed at Kisipachewuk Rapids (Fig. 2).

The Two-Mile Channel, approximately 425 ft wide and 25 ft deep, will be excavated by a hydraulic suction dredge and conventional means to improve discharge capacity between Lake Winnipeg and Playgreen Lake. Forest cover along the channel route has been cut and piled, and will be burned. Approximately 12.8 million cubic yards of primarily silty clay will be removed and deposited on either side of dykes bordering the channel. Mean velocity through the channel is estimated to be 2.0 ft/s, which will allow a permanent winter ice cover. Dredging will commence on the Two-Mile Channel in early 1974 and the channel is expected to be completed and operational in the fall of 1975.

The Eight-Mile Channel connecting Playgreen Lake to Kiskittogisu Lake is being dredged to improve discharge capacity between these two lakes. The Eight-Mile Channel will vary in width from 425 to 1000 ft, will accommodate a median velocity of 2.0 ft/s, and will require the removal of approximately 22.1 million cubic yards of primarily clay–peat material. Dyking on either side of the channel is designed to prevent dredge-spoil pumped onto the landscape from entering the channel. Dredging of the Eight-Mile Channel commenced in early 1972 and the channel is expected to be completed by late 1974.

The Ominawin By-pass is a channel excavated

to divert flows around the Ominawin Rapids to the West Channel. The Ominawin By-pass channel is approximately 2 miles long, 1000 ft wide, and 25 ft deep, and will require excavation of 8 million cubic yards of overburden and 650,000 cubic yards of rock by conventional means. Excavation should be completed in early 1974 and the channel operational in the latter part of 1974.

An estimated 10,000 cubic yards of rock has been excavated to increase flows through the Kisipachewuk outlet channel.

Kiskitto Lake regulation — A system of lesser dams and dykes required to improve hydraulic control and restrict flooding is associated with the West Channel Jenpeg control dam and the man-made channels. Kiskitto Lake will be controlled by a series of dams and dykes at the outlets from Kiskitto Lake to Black Duck Creek and the West Channel of the Nelson River (Fig. 2). Regulation will decrease the natural range of Kiskitto Lake level fluctuations from an historic natural range of 686.5–702.3 ft to elevations of 695.2–698.3 ft.

Churchill River Diversion

The works required for Churchill River diversion include construction of the Missi Falls control structure, the South Bay diversion channel, and the Notigi control facilities (Fig. 3).

Missi Falls control — A gated control structure and spillway at Missi Falls will be constructed by Manitoba Hydro to control the outflows of the Churchill River at Southern Indian Lake. Present water levels of Southern Indian Lake will be raised by approximately 10 ft to an elevation of 847 ft, the maximum elevation not to exceed 850 ft. A maximum drawdown or fluctuation of about 2 ft (845 to 847) is expected during any normal 12-mo period. Historically, Southern Indian Lake levels have fluctuated from a minimum elevation of 834.0 ft to a maximum elevation of 842.8 ft, maintaining an average long-term lake level elevation of about 836.5 ft.

With control, average outflows at Missi Falls will be reduced by approximately 80% to allow for average diversion flows of about 27,000 cfs to the Nelson River. In the past, outflows from Southern Indian Lake have varied from about 20,500 cfs to 92,000 cfs with a long-term mean of about 34,000 cfs. Churchill River flows at Hudson Bay will be reduced by approximately two-thirds of its historic average flow (45,000 cfs to 18,000 cfs).

Construction of the Missi Falls control structure is proceeding and impoundment of water is expected to begin in 1974. Flooding to the full supply level (847 feet) is expected to be completed by late 1975.

South Bay diversion channel — A diversion channel will be excavated from South Bay on Southern Indian Lake to Issett Lake on the headwaters of the Rat River to divert up to 30,000 cfs from the Churchill to the Nelson River. The channel will be approximately 5½ miles long and will maintain an average width of about 850 ft. Approximately 1 mile from Issett Lake the channel widens to 2500 ft to provide increased capacity. The depth of the channel varies from 23 to 32 ft to accommodate average flows at less than 2 ft/s velocity.

The channel route has been cleared of timber and excavation contracts have been awarded by Manitoba Hydro.

Notigi control — A control structure will be constructed at the south end of Notigi Lake to regulate upstream water levels and Southern Indian Lake at levels not exceeding 850 ft elevation. The Notigi control will release a maximum of 30,000 cfs to the Burntwood River.

Manitoba Hydro intends to use the natural inflow from the Rat River basin to raise water levels in the Notigi forebay from 790 to 832 ft by September, 1975. Further increased water levels (to 847 elevation) will be achieved by diverting waters from the Churchill River via the South Bay Channel, beginning November, 1975.

Historically, the Rat River at Notigi Lake has had an average annual flow of about 1100 cfs. With the Notigi Lake control, the Rat River will become part of an impoundment resulting from flooding of approximately 158 square miles, or 100,000 acres. The Notigi Lake control will maintain a head of from 20 to 30 feet. Annual maximum fluctuations in the forebay are likely to be insignificant, but occasionally may slightly exceed 5 ft. The minimum water level for the Notigi forebay area is defined by terms of license as 838 ft. Releases through the Notigi control will be such as to restrict maximum flows in the Burntwood River (at Thompson) to 34,000 cfs (the combined average historical mean flow of 4,000 cfs and diversion flows of 30,000 cfs).

Timber clearing associated with site preparation and construction activities has been completed.

Wuskwatim, Manasan, and First Rapids Generating Stations

Three generating stations identified as Wuskwatim, Manasan, and First Rapids, having a combined capacity of approximately 640,000 kw, have been proposed by Manitoba Hydro for development along the Burntwood River (Fig. 3). In addition to determining effects of the Rat–Burntwood diversion and to assist in Manitoba Hydro's long-term planning, the Study is expected to identify those environmental impacts attributed to future development of these generating sites. While planning and design of these structures are incomplete, Manitoba Hydro's preliminary calculations (based only on energy production values) show optimum forebay levels of 800, 690, and 610 ft, respectively, for these three generating sites.

Historically, mean monthly flows in the Burntwood River have ranged from a minimum of about 200 cfs to a maximum of about 19,000 cfs, with average annual flows of approximately 3,000 –4,000 cfs. These flows would be modified and controlled by the addition of the proposed generating sites. Annual fluctuations in forebay water levels at these sites would generally be in the order of magnitude of about 5 ft.

Other Hydroelectric Generating Sites

In addition to the facilities previously described, seven generating sites having a combined hydroelectric potential of approximately 5 million kw have been proposed for development by Manitoba Hydro: Long Spruce, Upper and Lower Limestone, Gillam Island, Upper and Lower Gull, and Bladder Rapids (Fig. 1).

Development of these proposed sites will probably have significant but more site-specific environmental impacts on the Lower Nelson River system. The Kelsey and Kettle generating stations have already imparted changes to this area.

Manitoba Hydro has given priority to development of generating sites on the lowermost stretch of the Nelson River. Kettle generating station is in the final construction phase with 9 of 12 turbines in operation; construction has begun at Long Spruce, and preliminary engineering works for development of Upper Limestone are underway.

Environmental Impacts

Environmental impacts of the proposed hydroelectric development of the Nelson River may be attributed to Lake Winnipeg regulation, Churchill River diversion, and future development of proposed generating sites along the Nelson River system. While this paper generally describes all aspects of the proposed Nelson River hydroelectric development, it chiefly concerns that portion of the development currently being investigated by the Study. Specifically, this involves studies to determine the effects of 1) the regulatory and control structures required for Lake Winnipeg regulation, 2) the control structures, diversion channel, and ancillary works required for Churchill River diversion, and 3) the three generating stations proposed for development in the longer term at Wuskwatim, Manasan, and First Rapids along the Burntwood River. It is anticipated that other studies will accompany and perhaps precede the development of other generating sites on the Nelson River. (A study of the effect of the hydroelectric development on the lower Nelson River has recently been approved by the Manitoba government.)

Lake Winnipeg Regulation

While it is recognized that the hydroelectric development will have immediate and long-term effects of varying magnitude on the total environmental complex, the assessment of environmental impact is somewhat facilitated by considering distinct geographical areas of impact in association with the various hydroelectric projects.

Lake Winnipeg — Lake Winnipeg regulation will significantly reduce the range of lake level fluctuations characteristic of this water body during the past 30 yr. Historically, Lake Winnipeg water levels have ranged from 709 to 717.5 ft. With regulation this range of water levels will be reduced to approximately 4 ft (711–715).

The reduced range of lake level fluctuation — a generally more stabilized lake level regime — is considered the most significant aspect of Lake Winnipeg regulation. Characteristics of the land–water interface will be influenced by Lake Winnipeg regulation. Physical and chemical changes may be expected to occur as a result of new dynamics of a more stabilized system.

The effects of regulation on marshes and beaches surrounding Lake Winnipeg, and associated implications to wildlife and recreation, have been identified as the most important environmental concern for this area. Changes in marsh productivity and availability of beaches may be related to the reduced and controlled range of lake levels. These changes may alter wildlife and

recreational use of marshes and beaches, respectively.

Wildlife studies currently in progress provide for an assessment of the importance of Lake Winnipeg marshes to wildlife, particularly waterfowl. Some attention has been given to a controlled system of marsh water levels specifically designed to maintain or improve marsh productivity and management. Information describing marsh productivity when correlated with Lake Winnipeg water level fluctuations is fundamental to an understanding of the impact of Lake Winnipeg regulation.

Results of studies designed to monitor shoreline erosion and sand movement will be used to predict the effect of Lake Winnipeg regulation on beach stability and availability. This information, when correlated with statistics on current and anticipated recreational demand for Lake Winnipeg beaches, will be used to describe some of the effects of Lake Winnipeg regulation on recreational use of this area.

The effect of any environmental change attributed to regulation on fish and fisheries of Lake Winnipeg is considered of relatively little importance during the short term. However, subtle and perhaps more significant ecological effects may be anticipated in the longer term as a result of a slow and gradual but persistent change in physical, chemical, and limnological characteristics of the lake associated with the more stabilized lake level regime. No attempt is being made in the current Study to monitor or model ecological changes associated with regulation of Lake Winnipeg.

The more obvious effects to real property, particularly stability of existing dyking, along the south end of Lake Winnipeg are being identified.

Relative to other environmental aspects of the proposed Nelson River hydroelectric development, the impact of regulation on Lake Winnipeg proper could be described as of generally lesser significance, particularly in terms of immediate economic and social implications. An accurate description of resource implications and associated socioeconomic and other environmental effects attributed to Lake Winnipeg regulation will require a comprehensive monitoring program.

Outlet Lakes — The term "Outlet Lakes" refers to those waters associated with the East and West channels of the Nelson River including lakes Playgreen, Little Playgreen, Kiskittogisu, Kiskitto, Cross, and others (Fig. 2). These lakes — particularly Cross, Kiskittogisu, and Kiskitto — and associated resources will be directly affected by construction and operation of the Lake Winnipeg control works.

While effects of the project on the landscape and associated resources in the Outlet lakes are of a relatively local nature and generally confined to a small area, impacts characteristic of the project in this area are, nevertheless, typical of most environmental impacts inherent to large-scale hydroelectric developments.

The Jenpeg control structure and channel development will alter the pattern of levels and flows of waters in this area. In some instances the range of lake level fluctuation will be decreased from the modified historic range of lake level fluctuation (Kiskitto Lake). In other areas regulation will cause levels of some lakes to occasionally exceed historic maximum and minimum levels (Kiskittogisu Lake). Most significant lake level and flow changes, however, will occur on Cross Lake where the historic pattern of seasonal high and low lake levels will not only be modified but reversed from the natural situation. These altered levels and flows may result in flooding, slumping, erosion, and other degradation of shorelines.

Modified patterns of levels and flows throughout the Outlet Lakes system may be expected to result in a changed ice regime for waters in this area. Of particular importance is the impact of the changed ice regime on river and lake shorelines.

Dredge-spoil from excavation of channels in the Outlet Lakes area may constitute a twofold problem: 1) degradation of the landscape within the area for dredge-spoil deposition, and 2) increased sediment loading of waters in close proximity to the dredge-spoil area. Particular attention has been given to increased sedimentation as a consequence of flows through these artificial channels. Studies are currently underway to monitor changes in the sediment load of neighboring waters.

The system of dams and dykes required for Kiskitto Lake control will tend to minimize lake level fluctuation. Erosion and sediment problems associated with controlled outlet flows and channel improvement are expected to be of minor importance.

The inundation of forested lands, particularly in the forebay area of the control structure and generating facility at Jenpeg, will have a significant environmental impact in terms of flooded timber. Selective clearing, while eliminating the unsightly appearance of flooded timber stands in some areas, may be expected to have detrimental effects in terms of shoreline instability, increased

degradation, and erosion of soils and material characteristic of the new reservoir, etc.

Water quality changes, attributed to erosion and sediment processes associated with altered patterns of water levels and flows and changed ice regime, can be anticipated.

Fisheries, wildlife, and recreation studies, while relatively restricted in scope, have been initiated primarily to determine the effects of altered water levels and flows and dredge-spoil distribution in this area.

Geological and archaeological inventories have been completed where flooding is anticipated.

The impact of perhaps greatest significance in this area is associated with the possible social implications to the Cross Lake community. Because the Cross Lake settlement is situated a short distance downstream from the Jenpeg control and power site, this community will be directly affected by changes in discharge from the control structure which will change water levels and associated ice conditions. Implications to life styles of residents of this remote community, particularly those associated with winter and summer transportation, have been given high priority in impact assessment for this area.

Churchill River Diversion

Southern Indian Lake — Lands bordering Southern Indian Lake and flooded to an elevation of 850 ft have been designated as that area directly impacted by the Manitoba Hydro project. As level fluctuations will be relatively restricted (about 2 ft during an average year), impacts associated with fluctuating water levels are deemed to be of lesser concern.

Shoreline and bank stability have been identified as two important features of environmental impact. Physical impact studies are in progress to determine the stability of island, lakeshore, and offshore areas subject to inundation. Further, a biophysical study of soil types, landforms, vegetative cover, permafrost, and drainage patterns of the area to be inundated has been completed to assist in describing the new anticipated land–water relationships. This information will provide for some interpretation of impact to aquatic and terrestrial ecosystems.

An inventory has been completed of the merchantable and nonmerchantable timber in the area to be inundated. A fringe of flooded timber around the lake proper and adjoining areas covering an estimated 135,000 acres will be one of the most obvious environmental impacts.

Geological surveys have been conducted in this area to determine implications of the hydroelectric development to future mining activities.

Archaeological investigations to identify sites have been undertaken, and excavation of some of the larger archaeological sites is in progress.

Fisheries and wildlife aspects have been given priority in environmental impact analysis, as many of the activities normally associated with residents of the community of South Indian Lake are dependent on these resources.

Socioeconomic evaluation of all aspects of the Manitoba Hydro project at Southern Indian Lake includes assessment of real property to be affected by increased water levels, transportation and navigation implications attributed to fluctuating and increased water levels and an altered ice regime, altered quality of water for domestic consumption, and the more complex social and economic interpretations of changes in resources, life styles, and cultural values.

Rat–Burntwood diversion — Major changes to the landscape associated with the Rat and Burntwood rivers and adjoining tributaries can be expected as a consequence of Churchill River diversion. Probably the most obvious physical impact will be recognized as the flooding of approximately 100,000 acres above the Notigi control structures, and the inundation of approximately the same area along the Burntwood River below the Notigi dam site as a result of diversion and the construction of Wuskwatim and Manasan power sites. Diversion without impoundment will cause significantly less flooding along the Burntwood River system.

As in other areas, data being collected from biophysical inventories and a physical impact study will be used in an attempt to predict anticipated changes to the natural land–water interface. Particular attention is being given to impacts associated with diverted flows, fluctuating water levels, and the associated ice regime.

Lands to be flooded along the Rat–Burntwood diversion route have been described and particular attention has been given to inventories of merchantable and nonmerchantable timber.

Similarly, a relatively large-scale archaeology inventory of potential sites to be inundated has been completed for this area. More intensive investigations, excavation, and recovery of archaeological material are currently being funded by Manitoba Hydro.

Limited geological surveys have been conducted in some areas of the lower reaches of the

Burntwood River to supplement the rather intensive geological investigations undertaken in the Southern Indian Lake and Rat–Burntwood areas during recent years.

Fisheries, wildlife, and recreation inventories and analyses of impact are being made for this area. Changes in fish and wildlife resources are of immediate and local importance to the residents of the Nelson House settlement. Recreational impacts are being considered within a regional/provincial framework.

Socioeconomic studies of the effects of hydroelectric development in this area have focused attention on the Nelson House community and Thompson. The more obvious and direct effects of the development in this area to real property, water quality for domestic municipal and industrial uses, local transportation and navigation networks, etc., have received specific attention in socioeconomic impact studies. More complex analyses required for interpretation of local, regional, provincial, and perhaps in some cases international socioeconomic effects are in progress.

Lower Churchill River — Significant reduction and fluctuations in flows in the Lower Churchill River and a major modification to the normal ice regime will combine to produce major changes in the physical and biological characteristics of this stretch of the river and associated resources. Implications to fish, wildlife, and recreational resources are considered to be the most important areas of impact. Numerous adverse effects are likely to accrue to fish and wildlife located along this stretch of the Churchill River. The altered flow regime and associated changes in river morphology and general appearance will significantly decrease the recreational attributes of the Lower Churchill River.

Studies are currently in progress to determine the impact of reduced flows on slush-ice formation in the Churchill River, as this may be an important factor in delaying closure of the Port of Churchill to navigation. Reduced flows may affect the quality of water required for municipal use at Churchill.

Other Impact Areas

The development of power generating facilities at other sites on the Nelson River (Long Spruce, Upper and Lower Limestone, Gillam Island, Upper and Lower Gull, and Bladder Rapids) will have relatively site-specific environmental impacts. Some of these sites have already been altered to some degree by the developments at Kelsey, Kettle, and Long Spruce.

Unlike the Churchill River diversion project, flooding attributed to development of these sites on the Nelson River is expected to be relatively insignificant. Sedimentation and erosion (particularly in areas of unstable river bank conditions, permafrost, etc.) will be important factors, however.

Particular areas of concern in future environmental impact assessment at these sites will probably be changes to water quality and fisheries, and socioeconomic aspects related to improved access to a hitherto inaccessible area. Other resources associated with and characteristic of the river and its uses will probably receive lower priority in environmental impact studies.

Regional development aspects may prove to be the most important consideration in any future environmental assessment program.

Summary

Planning, design, and construction of the proposed Nelson River hydroelectric development are in various stages of completion. In some instances, project design and construction are well advanced (e.g. Lake Winnipeg regulation) and detailed project specifications allow a relatively accurate description of the project and associated environmental impact. Less progress has been made in other areas of the hydroelectric development, tending to restrict the accuracy of environmental impact assessment (e.g. Churchill River diversion). Still other phases of the development are in such a preliminary stage of planning and design as to render any assessment of environmental impact at this time as mostly speculative, vague, and generally nondescript.

Two points should be noted with respect to the aforesaid description of the proposed development of the Nelson River. No attempt has been made to provide detailed information on: water levels, flows, and fluctuations; frequencies and probabilities of their occurrence; duration of flows and levels; timing and phasing of construction, etc. Rather, it is the intended purpose of this paper to present general information by which to better appreciate the nature and scope of the proposed development and associated studies. Secondly, information by which to describe the development is continually being updated, modified, and enhanced by Manitoba Hydro and others (e.g. the Study). Any interpretation based on the above data may be subject to change as new information is provided.

Environmental Impact of the Churchill Falls (Labrador) Hydroelectric Project: A Preliminary Assessment[1]

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DUTHIE, H. C., AND M. L. OSTROFSKY. 1975. Environmental impact of the Churchill Falls (Labrador) hydroelectric project: a preliminary assessment. J. Fish. Res. Board Can. 32: 117–125.

The Churchill Falls hydroelectric project in western Labrador involved the creation of reservoirs totalling 6650 km² in area and the diversion of two rivers: the Churchill and the Naskaupi. A considerable area of forest and muskeg was inundated. Flooding began in 1971 and full pond is expected in 1974. The nominal installed capacity of the scheme is 5.23 million kw, most of which will be transmitted via three 735-kv lines to the Hydro Quebec grid. The entire project will be completed by 1975.

The original feasibility studies for the project concentrated on a cataloging of fish and wildlife. Downstream effects of flow regulation were considered. Before hydroelectric development, the area was practically uninhabited and was given very little economic attention. A unique feature of ecological importance affected by the scheme is the vegetation of the spray zone around the falls. A study of the effect on this vegetation of closing the falls is in progress. A study of the impact of flooding on water quality and biology was begun before damming and will be continued indefinitely after impoundment. Preliminary findings show little evidence for humification or oxygen deficiency even in newly flooded areas, but conductivity and many dissolved ions have increased. Populations of both phytoplankton and zooplankton have generally increased and changed qualitatively with impoundment, particularly in shallow water. The primary productivity of the phytoplankton has increased significantly in flooded areas. The ecological impact on the Naskaupi River of the loss of its headwaters is being investigated. Other ongoing ecological studies at Churchill Falls include investigations on fisheries, wildlife, and forests.

DUTHIE, H. C., AND M. L. OSTROFSKY. 1975. Environmental impact of the Churchill Falls (Labrador) hydroelectric project: a preliminary assessment. J. Fish. Res. Board Can. 32: 117–125.

Le projet hydro-électrique des chutes Churchill du Labrador occidental a entraîné la création de réservoirs d'une superficie totale de 6,650 km² et le détournement de deux cours d'eau: le fleuve Churchill et la rivière Naskaupi. Une superficie considérable de forêts et de fondrières a été inondée. La submersion a commencé en 1971, et on s'attend d'avoir plein réservoir en 1974. La capacité nominale de l'installation, une fois terminée, est de 5.23 millions de kw, dont la plus grande partie sera transmise au réseau de l'Hydro-Québec, sur trois lignes de 735 kv. Le projet sera complété en 1975.

Les premières études de praticabilité qui ont précédé le projet se sont concentrées sur un catalogue des poissons et du gibier. On a examiné les effets en aval du réglage du débit. Avant le développement hydro-électrique, la région était pratiquement inhabitée, et plutôt négligée au point de vue économique. Un caractère unique d'importance écologique, affecté par le projet, est la végétation de la zone d'embruns au voisinage des chutes. On étudie présentement les effets de la fermeture des chutes sur cette végétation. On a entrepris, avant l'endiguement, une étude de l'impact de la submersion sur la qualité et la biologie de l'eau, étude qui se poursuivra indéfiniment, une fois le réservoir rempli. Les observations préliminaires ne fournissent que peu d'évidence de formation d'humus ou de carence d'oxygène, même dans les régions nouvellement inondées, mais la conductivité et plusieurs ions dissous ont augmenté. Les populations de phyto et de zooplancton ont généralement augmenté et subi des changements qualitatifs à la suite de l'endiguement, surtout dans les eaux peu profondes. La productivité primaire du phytoplancton a augmenté de façon significative dans les régions inondées. On est à étudier l'impact écologique sur la rivière Naskaupi de la disparition de sa source. Les autres études présentement en cours aux chutes Churchill portent sur les pêches, le gibier et les forêts.

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THE Churchill Falls project has received less critical attention from conservation groups and the public than perhaps any other recent large hydro project in Canada. There are several reasons for this: it is situated in a remote region which before development was unpopulated; it has not threatened the economy or culture of any group of native people; and there is no single large concrete structure upon which attention may be focused. However, the physical changes to the environment have been considerable. A large area of boreal forest and spruce-tundra has been flooded, the headwaters of the Naskaupi River have been diverted, and the flow of water over Churchill Falls itself has been limited. Public attention to the last has been slight, possibly because the number of people who had seen the falls prior to diversion number only a few hundred. Also, it appears to have been generally recognized that diversion of the falls was a small price to pay for the economic benefit of the scheme.

The purpose of this paper is, first, to present a general account of the hydroelectric development, and second, to describe the impact of the project on the ecology of the region. The second must be considered preliminary; the project itself is incomplete and the main reservoir is not expected to reach full pond before summer 1974. Most of the ecological studies are also incomplete. Only a brief outline is possible at this stage but it should be sufficient to provide some concept of their scope and direction. An exception is the water quality and biology study carried out by the authors over the period 1970–73. The completed results from this study are more fully reviewed, and include the immediate impact of flooding on water chemistry, phytoplankton, zooplankton, and primary productivity.

A physical description of the area, including geography, geology, climate, and vegetation is given in Duthie and Ostrofsky (1974), who also described the limnology of the region prior to the formation of Smallwood Reservoir.

HYDROELECTRIC DEVELOPMENT

Prior to hydroelectric development most of the region was uninhabited. The trapping of fur bearing animals was based on settlements on the Quebec or Labrador coast. In the northern regions caribou were hunted seasonally by native peoples until very recently. There are a few seasonally operated fishing and hunting camps, accessible only by aircraft. The iron ore mining towns of Schefferville, Wabush, and Labrador City are on the western edge of the watershed and are serviced by a railway from Sept-Iles on the St. Lawrence (Fig. 1). The town of Twin Falls was founded in 1960 and the town of Churchill Falls was founded in 1967 at the start of work on the hydroelectric project. They are linked by tote roads to the port of Goose Bay to the east and the railway to the west. The area is linked to Montreal and St. John's by commercial airlines.

The Labrador plateau has been likened to a shallow saucer with notches in its rim through which it drains. Most of this drainage is through the Churchill River. By means of diversions the water which normally cascades over the falls has been retained on the plateau and channelled to turbines above the river and east of the rapids and falls (Fig. 2). That point is only about 2 km from the river but is over 300 m higher.

The main reservoir, Smallwood Reservoir, has been formed behind a series of low dykes some 80 km upstream from the power plant. Flow from Smallwood Reservoir to the forebay and the intake is regulated by a series of control structures as indicated in the figure.

The other major notches in the saucer are the Naskaupi and the Twin Falls (Unknown) rivers. A series of dykes has diverted the natural outlet of Michikamau Lake to the Naskaupi River, diverting it westward to the Churchill Basin. Michikamau Lake and its flooded environs form most of the eastern portion of Smallwood Reservoir.

FIG. 1. A portion of eastern Canada showing location of the reservoirs and the Churchill River.

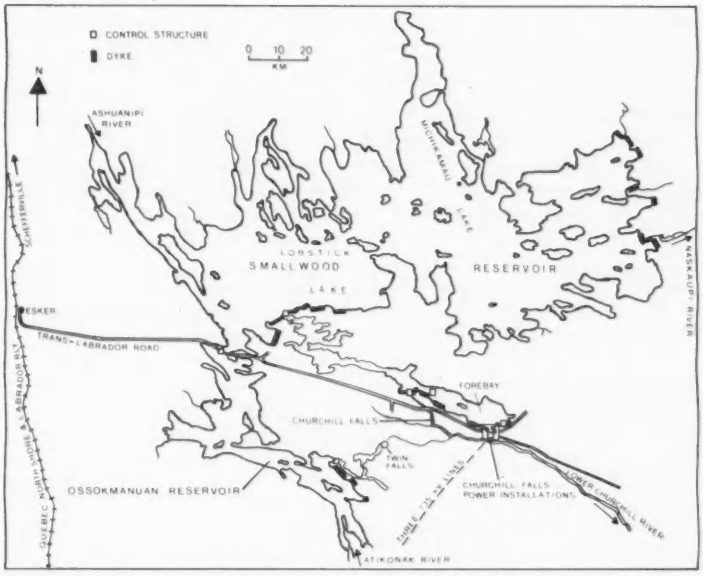

Fig. 2. Project area showing reservoirs and installations.

A small portion of the headwaters of the Kanairiktok River has also been diverted by dykes to form the extreme northeast lobe of the reservoir. Ossokmanuan Reservoir in the south of the plateau was formed in the early 1960s by the construction of the Twin Falls hydroelectric plant on the Unknown River. Eventually, water from the Twin Falls–Ossokmanuan Reservoir will be diverted into the Smallwood Reservoir. Thus the Smallwood Reservoir, in addition to its natural drainage from the Ashuanipi River basin, will as a result of diversions receive waters from three other basins: the Atikonak–Ossokmanuan, the Naskaupi–Michikamau, and a small portion of the Kanairiktok drainage.

The natural drainage area of the upper Churchill basin (above the falls) was 56,000 km², now increased to 69,000 km² by diversions. The total area of Smallwood Reservoir is expected to be 5,700 km² at full pond, and the maximum area of Ossokmanuan Reservoir 950 km², for a total reservoir area of 6,650 km². We estimate that about 60% of the area of Smallwood Reservoir was formerly water and the remainder flooded forest, muskeg, and barrens. Likewise, about 75% of the area of Ossokmanuan Reservoir was formerly water. The average annual drawdown is about 4.0 m in the Smallwood Reservoir and about 3.5 m in the Ossokmanuan Reservoir.

The gross head of water at the power site is 323 m and the regulated flow rate is expected to be 1,390 m³/s. The ratio of annual outflow to stored volume is estimated to be 1.4:1. Churchill Falls will have a nominal installed capacity of 5.23 million kw (7 million hp) in 11 units of 475,000 kw each and will produce about 34.5 billion kwh/yr. Most of the power will be transmitted via three 735-kv lines to Hydro Quebec (Fig. 2). The entire project is expected to be completed by 1975.

The Impact of Flooding on Water Chemistry and Biology

Water Chemistry

Ossokmanuan Reservoir — Ossokmanuan Reservoir was formed in 1962 by damming and raising the level of some lakes in the lower Atikonak River basin. As no preimpoundment limnological data exists, the impact of flooding must be judged by comparison with Atikonak Lake, upstream and unaffected by flooding. Ossokmanuan Reservoir is similar chemically and biologically to Smallwood Reservoir so may serve as a model with which to predict the possible development of the latter.

Typical analyses (summer 1970) at two sta-

tions in Ossokmanuan Reservoir and in Atikonak Lake are shown in Table 1. The influence of the bedrock appears to play a greater part in determining the chemistry of Ossokmanuan Reservoir than flooding. Gabbro bedrock, found only under the north arm, is more readily weathered and contains more calcium and magnesium than the granite and gneiss bedrock of the southeast arm and Atikonak Lake. Thus the north arm has a higher conductivity and alkalinity. Both stations in Ossokmanuan Reservoir are less colored than Atikonak Lake; phosphorus is slightly lower, and nitrate (in the north arm) slightly higher. Thus 8 yr after flooding the chemistry was very little different from that of the unflooded Atikonak Lake. Perhaps the only significant factor was the lower minimum oxygen concentration.

In describing reservoirs in the Karelian S.S.R. (a region similar to western Labrador), Baranov (1961) describes the following development. The trophic upsurge phase following flooding of vegetation and soils is modified by the inflow of acid humic material from flooded bogs (humification). Phosphorus and nitrogen may rise and an oxygen deficit may develop near the bottom. This phase lasts 5 or 6 yr. Following the exhaustion of nutrients a period of trophic depression sets in and may last 13 yr. About 20 yr after flooding the third phase sets in, characterized by a gradual increase in the mineral content of the water, increasing productivity, and a return to an orthograde oxygen curve.

In comparison with the Karelian reservoirs it is possible that Ossokamanuan Reservoir is entering the trophic depression phase. The only clear evidence of flooding is oxygen undersaturation near the bottom during the winter months. This condition rapidly disappears after spring breakup. There is no evidence of humification. Visual observation confirms that only the woody parts of the flooded vegetation remains.

Smallwood Reservoir — The following is based on analyses made in 1970 before flooding and in 1973 when the reservoir was approaching full pond level. Flooding began in 1971. Typical analyses, shown in Table 2, are from three lake stations unaffected by flooding and the same three stations after flooding and incorporation into Smallwood Reservoir.

The 1970 survey revealed two regions of broadly differing water chemistry within the boundaries of the future reservoir; the upper Churchill basin and the Naskaupi basin (Duthie and Ostrofsky 1974). The upper Churchill basin, now the western part of the reservoir, was typified by conductivities around 15–20 μmho/cm, alkalinities 7–12 mg/liter $CaCO_3$ and pH between 6.3 and 6.5. The Naskaupi Basin, now the central and eastern part of the reservoir, had the most dilute waters on the plateau. Conductivities were generally between 10 and 12 μmho/cm, alkalinities 5.5–6.5 mg/liter $CaCO_3$, and pH around 6.0. Michikamau Lake differed from Fremont Lake (on the extreme east) by its transparency and low color.

Water color decreased in the western part of the reservoir but increased a little in Michikamau and the eastern part. The Secchi disc transparency decreased at all three stations, while conductivity, pH, and alkalinity all increased. Nitrate nitrogen shows the greatest change, increasing 3.3 fold in Michikamau Lake, 2.5 fold in Lobstick, and 1.5 fold in Fremont. Accurate phosphate phosphorus determinations were not made in 1970; current concentrations decline eastward.

There is no evidence yet of humification or of an oxygen deficit.

The impact of flooding on the measured parameters is fairly small, except possibly with nitrate. This is not surprising given the relatively low nutrient status of the soils and the poor vegetation. The fairly high flushing rate in the reservoir would inhibit the accumulation of the products of decomposition. Also, oxygenation is encouraged by the polymictic nature of the lakes.

Phytoplankton Composition and Biomass

Before impoundment the phytoplankton of most lakes in the Churchill Falls area was dominated by species of *Dinobryon*, in particular *D. divergens* and *D. bavaricum*, and several diatom species such as *Asterionella formosa*, *Tabellaria fenestrate*, *Rhizosolenia eriensis*, *Melosira islandica*, and *M. italica* subsp. *subarctica*. Shallow lakes and lakes with dentritic or boggy shorelines had a greater diversity of species than deep lakes. The richest lake in number of species was Ossokmanuan Reservoir but the dominant species were as above; the only major difference from unflooded lakes was the increased importance of *Dinobryon* spp. and reduced importance of diatoms (Duthie and Ostrofsky 1974).

In June 1972, during the initial flooding of the Lobstick Lake area of Smallwood Reservoir, the typical diatom–*Dinobryon* assemblage was replaced by a group of cyanophytes; mainly *Dactylococcopsis irregularis*, *D. acicularis*, and *Oscillatoria limnetica*. This was particularly noticeable in newly flooded inshore areas. As the season

TABLE 1. Typical summer physical and chemical values for Atikonak Lake (unaffected by flooding) and two stations in Ossokmanuan Reservoir. All three sites are in the Atikonak River basin.

Station	Color Hazen units	Secchi disc visibility (*m*)	Conductivity		Minimum O_2 % saturated	Alkalinity mg/liter $CaCO_3$	PO_4-P mg/liter	NO_3-N mg/liter
			μmho/cm	pH				
Atikonak Lake	30	3.5	16	6.1	95	7.2	.006	.023
Ossokmanuan Reservoir (southeastern)	20	3.5	13	6.4	95	6.8	–	.021
Ossokmanuan Reservoir (north arm)	15	4.5	32	6.2	77	16.0	.004	.028

TABLE 2. Comparison of some midsummer physical and chemical parameters at three lake stations before flooding (1970) and after flooding (1973).

Station	Color Hazen units	Secchi disc visibility (*m*)	Conductivity		Minimum O_2 % saturated	Alkalinity mg/liter $CaCO_3$	PO_4-P mg/L	NO_3-N mg/liter
			μmho/cm	pH				
Lobstick Lake, 1970	23	4.25	16.5	6.3	85	7.7	–	.024
Smallwood Reservoir (west), 1973	10	3.75	24.7	6.7	91	10.0	.007	.060
Michikamau Lake, 1970	0	13.00	11.0	6.1	95	6.1	–	.018
Smallwood Reservoir (central), 1973	10	6.00	13.0	6.5	100	7.0	.003	.060
Fremont Lake, 1970	5	8.25	12.8	6.0	90	6.0	–	.019
Smallwood Reservoir (east), 1973	10	4.25	13.8	6.5	90	6.1	.002	.030

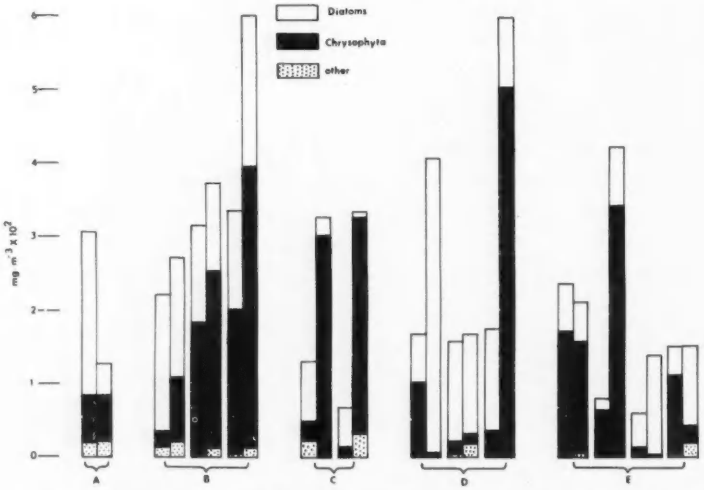

FIG. 3. Maximum phytoplankton biomasses and composition at 13 stations in lakes and reservoirs on the Labrador Plateau in 1970 (*left-hand columns*) and 1972 (*right-hand columns*). A, Atikonak Lake (unflooded); B, Ossokmanuan Reservoir, three stations (flooded 1962); C, D, and E: Smallwood Reservoir (flooding began in 1971); C, Northwest arm, two stations; D, West basin, three stations; E, East basin, four stations.

progressed, however, the cyanophytes declined in importance. This immediate change in the phytoplankton composition is apparently not typical of new reservoirs. For example, Rodhe (1964) found little change in the phytoplankton during the initial flooding of an oligotrophic lake in northern Sweden. Here it is possible the cyanophytes were derived from innundated bogs.

The impact of flooding on phytoplankton biomass is illustrated in Fig. 3. In general, biomasses have increased, but not to any consistent degree; it is possible a clearer picture will emerge after further observation.

Ossokmanuan Reservoir generally has the highest phytoplankton biomass of the lakes studies; the maximum is usually 2 or 3 times that of nearby natural lakes. The initial response of the phytoplankton of Lobstick Lake to flooding was not an immediate increase. On the contrary, the biomass declined from about 500 mg/m^3 to about 50 mg/m^3 during the initial period of rapid flooding in the summer of 1972. This decrease may be partially explained by dilution and also the high turbidity. Results from 1973 from Smallwood Reservoir suggest a several fold increase in phytoplankton biomass over preimpoundment levels, mainly as a result of a "bloom" of *M. islandica*, and a reduction in turbidity.

PRIMARY PRODUCTION (FIG. 4)

Michikamau Lake — Production rates measured during the summer of 1971 ranged from 135 to 197 mg C/m^2 per day. The production:depth curve shows no distinct maximum; this is typical of highly transparent lakes. The major species throughout the summer were *Dinobryon bavaricum* and *A. formosa*. Flooding of Michikamau Lake began in 1971. It is not known to what extent this affected the primary production. The maximum phytoplankton biomass, 164 mg/m^3, was higher than that of 1970 (70 mg/m^3) before flooding, though it may not be possible to place significance on such low values.

Atikonak Lake — This lake drains into Ossokmanuan Reservoir via the Atikonak River and is unaffected by flooding. The areal production rates in 1971, 81–127 mg C/m^2 per day, are comparable to Michikamau, although Atikonak Lake does not exceed 8 m in depth. A pronounced maximum was usually found at .5 m, typical of humic lakes. Optimum hourly rates were 5.5 mg C/m^3. Phytoplankton populations were usually compara-

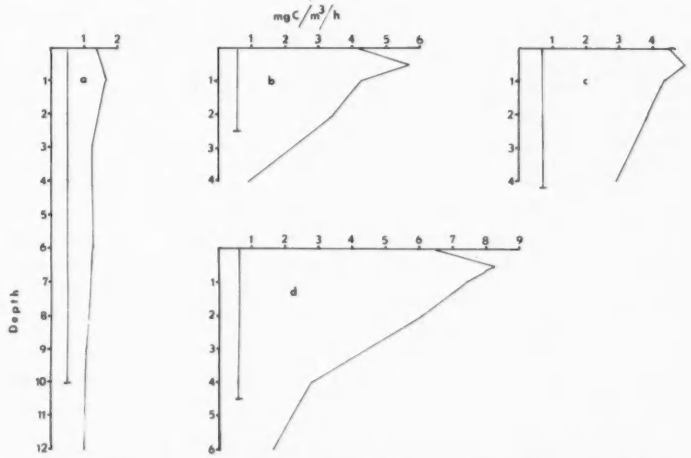

FIG. 4. Typical midsummer primary production vs. depth curves from four Labrador lakes. Secchi disc transparency is also indicated. a) Michikamau Lake, August 10, 1971. Day estimates 135 mg C/m². Phytoplankton biomass 37 mg/m³; b) Smallwood Reservoir, west basin, August 18, 1972. Day estimates 93 mg C/m². Phytoplankton biomass 262 mg/m³; c) Atikonak Lake, September 19, 1971. Day estimate 127 mg C/m². Phytoplankton biomass 346 mg/m³; d) Ossokmanuan Reservoir, August 8, 1971. Day estimate 213 mg C/m². Phytoplankton biomass 446 mg/m³.

tively high and were dominated by the typical *Dinobryon*–diatom assemblage, but perhaps because of the shallowness of the lake the plankton contained many tychoplanktonic and littoral forms. The maximum observed biomass was 346 mg/m³.

Ossokmanuan Reservoir — Primary production rates in 1971, 10 yr after impoundment, were the highest of the lakes in the region, reaching 267 mg C/m² per day. There was generally a pronounced maximum at .5 or 1 m depth with optimum hourly rates as high as 9.0 mg C/m³.

Smallwood Reservoir (Lobstick Lake) — Production rates were measured in 1972 during the actual process of flooding. The increase in turbidity and reduction in phytoplankton standing crop was mentioned above. Probably because of these factors the areal primary production was comparatively low, 67–163 mg C/m² per day, and no significant photosynthesis took place below 4 m. On the other hand, the pronounced maximum at .5 m (usually) was the highest in the region, reaching 9.0 mg C/m³ per hour.

Apparently the immediate effect of impoundment is a decrease in areal production rates due largely to increased turbidity and smaller standing crops. The long-term effect is a several fold increase due to decreased turbidity, increased nutrients, and increased standing crops of phytoplankton.

ZOOPLANKTON

Populations of the more abundant species are shown in Table 3. Interpretation of the effect of flooding based only on the 1973 observations is risky; several years are needed to confirm trends and reveal variations due to factors other than flooding. For example, 1973 was an exceptional year in several respects: the spring thaw was early, the summer was warm and sunny, and some populations in unflooded lakes such as Atikonak were exceptionally high.

Ossokmanuan Reservoir generally has comparatively high populations of *Diaptomus minutus*, *Bosmina coregoni*, and some *Daphnia* spp. Increased populations of particulate feeders in the first few years following impoundment have been reported by several authors. Among the nonherbivores, either *Cyclops scutifer* or *Mesocyclops edax* is usually dominant. Most of the common species show considerable variation between the years suggesting that stabilization in the reservoir has not been established.

In Lobstick Lake the large increases in most populations between 1970 and 1973 may be interpreted as evidence for trophic upsurge following inundation. The increase in particulate feeders

TABLE 3. Maximum observed seasonal populations (no. per m^3) of some zooplankters in 1970 (four lakes), 1971 (three lakes), and 1973 (four lakes). A dash (–) = not seen. Atikonak Lake is unflooded; Ossokmanuan Reservoir was filled in 1962; flooding began in Smallwood Reservoir in 1971 and full pond is expected in 1974.

							Smallwood Reservoir				
	Atikonak Lake			Ossokmanuan Reservoir			Lobstick Lake		Michikamau Lake		
Species	1970	1971	1973	1970	1971	1973	1970	1973	1970	1971	1973
Diaptomus minutus	264	840	3332	1392	2304	1054	414	4312	550	730	3013
Bosmina coregoni	736	504	3500	2568	1316	4154	782	3192	377	390	782
Daphnia longiremis	372	462	< 50	1848	1400	2015	1426	2352	< 50	< 50	483
Daphnia galeata mendotae	372	420	364	1344	1080	5859	414	1064	< 50	–	< 50
Daphnia pulex	72	336	672	60	282	682	< 50	2856	–	–	–
Cyclops scutifer	< 50	630	1260	256	235	2232	< 50	< 50	261	730	414
Mesocyclops edax	96	< 50	84	672	< 50	155	< 50	7392	–	–	–
Epischura lacustris	120	< 50	112	50	< 50	< 50	50	112	87	< 50	50

is especially evident. Of the other species, *M. edax* showed the greatest response. Its maximum population of 7392 individuals/m^3 is the highest population of any crustacean in any of the Churchill Falls lakes investigated.

As stated elsewhere in this paper, Michikamau Lake differs in several ways from other lakes in the region; the zooplankton is no exception. Even after flooding most populations remain low, and several species common in the other lakes are absent or rare. *Diaptomus minutus* shows the greatest response, with lesser increases in *B. corregoni* and *Daphnia longiremis*. The extent to which these modest increases are due to flooding and not due to other factors is unknown. The chief predator remains *C. scutifer*, though its population apparently declined from 1971.

Summary of Other Ecological Investigations

Since the beginning of construction the Churchill Falls (Labrador) Corporation Ltd. has demonstrated its environmental responsibility by encouraging or supporting several projects. A full-time biologist was retained by the company in 1973. The water quality and biology study described here was begun in 1970 under the auspices of the Conservation Coordination Group of the Corporation and is the most complete to date. Several other projects of an environmental nature initiated either by the committee or by independent scientists are briefly described below. Most will probably continue for several years.

A detailed study of the flora of the spray zone of Churchill Falls has been made since 1970 (Brassard et al. 1971). The area influenced by the spray zone has provided an unusual habitat and refuge for a unique association of species. Flow over the falls ceased in August 1971 and since then some changes have been evident in growth and species composition (Olsen 1973). Studies are also being made on the bryoflora (Brassard 1972).

The two rivers most affected by the schemes are the Lower Churchill and the Naskaupi. Hydrological studies are continuing on both rivers. Unlike the Churchill, which now drains a larger area as a result of diversions and has a regulated flow, the Naskaupi has lost some 7000 km^2 of its headwaters in the Michikamau Lake area. There have been two major effects — on stream flow and on water quality. The river channel is almost dry as far downstream as Wuchusk Lake, about 90 km below the dykes. Due to many tributaries and lakes along its course below Wuchusk Lake, the lower Naskaupi is not as much affected. Since dyke closure in 1971, alkalinity, calcium, nitrogen, sulfate, and chloride have risen as a result of the elimination of the extremely dilute Michikamau headwaters. The effect of flow reduction and changes in water chemistry on fish populations has been studied by Environment Canada.

There are several ongoing studies on wildlife. Most of the 42 species of land mammals in Labrador are found in the Churchill basin. One study on caribou is mainly directed toward estimating the population, distribution, and migration habits of the herds, and the impact of impoundment. Moose were never common on the Labrador plateau, except possibly in the Atikonak region. The impact on moose populations of the proposed hydroelectric development of the lower Churchill is being evaluated. The impact of impoundment on populations of small mammals is being investigated. A study of fish species and populations in the Smallwood Reservoir was initiated in 1972 using a converted fishing boat purchased by the corporations. Other studies include work on birds (mainly ducks and geese) and biting insects.

Forest growth in the Churchill basin is generally poor and there has been no commercial exploitation. It has been estimated that only about 2% of the timber in the flooded basin was marketable. Investigations on the forests include photogrammetry and mapping of vegetation and estimations of the decay rate of flooded trees. Growth of trees and other vegetation takes place right up to the edge of the reservoir. Gleying and waterlogging of soils which has occurred with some Russian reservoirs has not occurred on the impermeable shield bedrock.

Acknowledgments

We gratefully acknowledge the Churchill Falls (Labrador) Corporation Ltd. for providing information essential to this paper.

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Ecological Consequences of the Proposed Moran Dam on the Fraser River[1]

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GEEN, G. H. 1975. Ecological consequences of the proposed Moran Dam on the Fraser River. J. Fish. Res. Board Can. 32: 126–135.

The details of a high-head dam often proposed for the Fraser River are presented. The anticipated effects of such a development are considered. Changes in temperature, flow, and turbidity regimes would likely reduce the growth or survival of young salmon in both the lower river and the Strait of Georgia.

Nitrogen supersaturation would affect both adults and young salmonids for a considerable distance below the dam. Satisfactory and economical methods for transporting large numbers of adult salmon upstream over a dam without undue delay have not been developed. Further, no dependable system is available for trapping young downstream migrants in the reservoir. Losses of young through residualism and predation in the reservoir and spillway or turbine mortality would be high.

Viable alternatives to natural production that would ensure the maintenance of upstream stocks of salmonids such as sockeye (*Oncorhynchus nerka*) and chinook (*O. tshawytscha*) salmon do not presently exist. It is concluded that a high-head dam on the main stem Fraser River would result in the elimination of upstream stocks and contribute to a decline in some downstream stocks.

GEEN, G. H. 1975. Ecological consequences of the proposed Moran Dam on the Fraser River. J. Fish. Res. Board Can. 32: 126–135.

L'auteur donne les détails d'un projet de barrage à haute charge souvent mis de l'avant pour le fleuve Fraser. Il examine les effets anticipés d'un tel développement. Les changements de température, de débit et de turbidité sont susceptibles de retarder la croissance et de diminuer la survie des jeunes saumons, tant dans le cours inférieur du fleuve que dans le détroit de Géorgie.

La supersaturation d'azote affecterait à la fois les adultes et les jeunes salmonidés sur une distance considérable en aval du barrage. On n'a pas encore trouvé de méthode satisfaisante et économique pour le transport, sans trop de délai, d'un grand nombre de saumons adultes par-delà un barrage. De plus, on n'a pas encore à sa disposition d'engin de capture, dans le réservoir, des jeunes qui descendent vers la mer. La destruction des jeunes par emprisonnement ou prédation dans le réservoir, ou par mortalité dans les déversoirs ou les turbines serait considérable.

Il n'y a pas à l'heure présente d'alternatives viables à la production naturelle pour assurer le maintien, en amont, des stocks de salmonidés tels saumons nerka (*Oncorhynchus nerka*) et chinook (*O. tshawytscha*). Nous en concluons qu'un barrage à haute charge sur la branche principale du fleuve Fraser aurait pour effet d'éliminer les stocks d'amont et contribuerait au déclin des stocks d'aval.

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FOR at least 25 yr there have been proposals to generate large quantities of electricity at a high-head dam at Moran Canyon on the Fraser River. In 1955 such a development was proposed to foster growth of metallurgical industries in the area. On several occasions, more recently, similar schemes have been proposed as methods of flood control on the Fraser River and generation of additional electricity for a growing British Columbia population. At present there seems to be little likelihood of an early development at Moran Canyon. The B.C. Energy Board (1972) reviewed energy requirements in the province until 1990 and identified a number of sites for possible hydroelectric generation but excluded Moran Canyon because of the great impact a development would have on economically important fish populations. However, the current energy situation might lead to renewed interest in a development at Moran Canyon.

This paper has been prepared to bring together the literature relating to the biological consequences of a high-head development at Moran Canyon. This subject has been under intensive though intermittent study for more than 20 yr. Even if development at Moran Canyon is not

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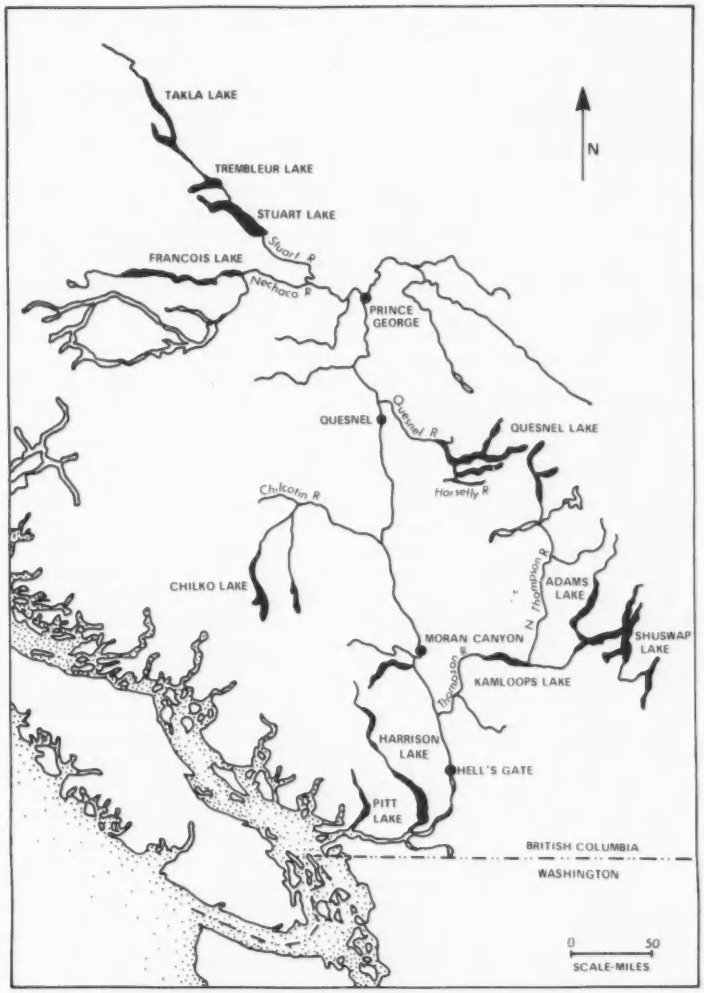

FIG. 1. The Fraser River system showing the salmon-rearing lakes (darkened) and the location of Moran Canyon.

imminent, many of the anticipated effects are sufficiently general that they would apply to high-head developments on other B.C. salmon rivers as well as to systems not supporting anadromous fish stocks.

Characteristics of the Proposed Moran Dam

The location of the proposed Moran Dam is shown in Fig. 1. The site is on the main stem of the Fraser River approximately 37 km upstream from Lillooet and 365 km from the mouth of the river. Details of the proposed development have varied from time to time. The most recent proposals are those incorporated in the B.C. Energy Board Report (1972). The dam would have a head of 215 m. Power intake towers would be 60 m below full-pool elevation of 456 m. Seasonal drawdown would be at least 45 m and was as much as 88 m in the scheme suggested by the Fraser River Board (1958). The Moran Dam would flood approximately 270 km of the Fraser

River to a point near Quesnel. The reservoir at full pool elevation would have a surface area of 242 km^2 and total storage of 1.5×10^{10} m^3. Active storage would be 7.8×10^9 m^3. Full generation capacity would be 3750 MW. Provision for spilling excess flows of up to 23,500 m^3/s would be provided by a gated 8-bay spillway. Average unregulated flow of the Fraser River at Moran Canyon is 1650 m^3/s. The development would lead to a major change in the daily and seasonal flow regime. To minimize the short-term effects of discharge from a Moran-type dam, a reregulating dam located approximately 32 km downstream has been proposed. It would have a 37-m head, a 6.6-m drawdown, a surface area of 5.2 km^2, and active storage of .03 km^3. Power generated at this facility would increase the capacity of the Moran development to 4350 MW. Total capital cost of the development has been estimated at $881 million (B.C. Energy Board Report 1972). Additional details of the features of the proposed Moran Dam are to be found in Anon. (1971) and the B.C. Energy Board Report (1972).

The proposals for hydroelectric development at Moran Canyon have led to considerable concern within the government agencies responsible for management of resident and anadromous fishes. The Pacific salmon populations spawning in the Fraser River are of major economic significance as they support large salt water commercial and sports fisheries and important food and commercial fisheries on the river. Any development which might reduce the size of these stocks is of justifiable concern.

Five species of Pacific salmon (*Oncorhynchus* sp.) spawn in the Fraser River and its tributaries. The sockeye (*O. nerka*) and chinook (*O. tshawytscha*) are two species which are abundant above Moran Canyon. In addition, there are indications that pink salmon (*O. gorbuscha*) stocks are expanding into some upriver areas. The coho (*O. kisutch*) and chum (*O. keta*) salmon are usually found only in the streams and rivers tributary to the lower reaches of the Fraser River. The anadromous steelhead trout (*Salmo gairdneri*) also spawns in the Fraser River and its tributaries above Moran Canyon.

The mature sockeye return to their home stream in late summer or fall, spawn and die. The young on emerging the following spring move into a rearing lake in which they spend at least a year before moving to the sea at a size of 10–15 cm. Most attention will be devoted to sockeye salmon in this paper since the most thorough evaluation of the possible consequences of a Moran-type dam on fish has been directed to this species.

Historically sockeye salmon populations in the area above Moran were very large. The catch of Fraser River fish from 1894–1913 averaged 751,617 cases (about 8.5 million fish) which was largely made up of the early runs originating from the upriver areas. Sockeye stocks dropped dramatically after 1913 as a result of a slide at Hell's Gate and did not begin to increase again until 1945 when fishways were constructed at Hell's Gate and careful management techniques applied.

The stocks in most upriver areas have shown a dramatic increase since that time although in total they are still well below the numbers recorded at the turn of the century. Average escapement to the areas above Moran Dam was 564,000 sockeye between 1946 and 1969, while average catch of fish from these stocks was 1.9 million during the same period. This catch had an average value of $8.9 million (Anon. 1971).

On the basis of rearing potential of the lakes, Larkin and Ricker (1964) estimated a potential catch of 14.5 million Fraser River sockeye annually. From this and other lines of evidence, it has been suggested that an average annual catch of 7.76 million sockeye is a conservative estimate of the potential production of the rearing areas upstream from Moran Canyon (Anon. 1971). This catch would have a packed value of close to $50 million at present prices. On any given year escapements upriver which now occasionally exceed 1 million fish might readily be doubled or tripled. The design of fish passage facilities or alternatives to natural production at a Moran-type dam would have to be undertaken with the potential of these stocks in mind.

The other species of anadromous salmonids are much less abundant in the upriver areas. Pink salmon show signs of establishing upstream spawning populations. The potential for increase is unknown although it may be considerable. Relatively little information is available on the size of spawning populations of chinook salmon or steelhead trout. It has been suggested that one-third of the catch of Fraser River chinooks (about 160,000) originates above Moran Canyon (Anon. 1971), although those estimates are admittedly crude. Populations of steelhead above Moran Canyon are estimated at 10,000–25,000 fish.

The review to this point indicates that large populations of anadromous salmonids spawn

above Moran Canyon and that considerable potential exists for an increase in stock size. These species and particularly the sockeye, support a large commercial fishery in the Fraser River and the Gulf of Georgia. In addition perhaps 100,000 adult salmon are taken annually for food in a river fishery by native Indians. The chinook salmon originating above Moran Dam undoubtedly contribute to an important sport fishery in the Gulf of Georgia.

Environmental Changes Produced by Construction of a Moran-type Dam

The most obvious change produced by a high-head dam at Moran Canyon would be the flooding of approximately 270 km of river. Velocity of water flow through the reservoir would be markedly reduced to the point that travel time of water through the reservoir might be about 2 mo in the May–June period compared with 1–2 days at present.

Undoubtedly the existence of the reservoir would alter water temperatures. It has been predicted (Andrew and Geen 1960; Anon. 1971) that the reservoir would stratify during the summer. Water passing through the turbines would be hypolimnetic and have lower temperatures than present downstream summer temperatures. Present August temperatures at Hell's Gate, approximately 150 km downstream, range from 15–19 C. If Moran Dam were constructed it has been estimated that temperatures would range 13.5–16.5 C. Conversely, downstream water temperatures would be somewhat higher (perhaps 2–3 C) in the October–November period than presently.

Turbidity would be reduced if a Moran-type dam were constructed on the Fraser River. The concentration of suspended sediment has a seasonal pattern ranging from 20 ppm in winter to 800 ppm just before the peak of spring discharge (Anon. 1971). Kidd (1953) has estimated that 85–95% of the suspended sediment in the river would settle in the reservoir. This could amount to 15×10^6 tons per annum.

The normal discharge pattern of the Fraser River downstream from Moran Dam would be dramatically changed although total annual discharge downstream would remain the same. A large net increase (46–114%) in river flow at Hope would occur from December–April, the period of normal minimum flow. Downstream flow would be reduced in the May–July period and would change very little in the August–October period. Only the flow from December to April would be consistently above the range encountered normally.

It has been suggested (Anon. 1971; Andrew and Geen 1960) that dissolved oxygen in the reservoir would be comparable to that in a large oligotrophic lake and not likely to show appreciable depletion, even at great depths. However, in summer, both oxygen and nitrogen would likely be supersaturated at 10 m below the reservoir surface. Supersaturated water could well be drawn through the turbines. Further supersaturation would be expected to result as water was spilled from the reservoir. This supersaturation would persist for a considerable distance downstream. Data from the Columbia River suggest that it may require at least 75 km before equilibration is approached in the river downstream from the proposed dam.

Effects of Downstream Changes

For purposes of discussion the effects of downstream changes on fish in the river are considered separately from possible effects on conditions in the Strait of Georgia, the coastal area into which the Fraser River flows and in which young salmon of all species spend their first few months of marine life.

(a) *Strait of Georgia* — The effects of construction of a Moran-type dam on productivity of the Strait of Georgia have been reviewed by Parsons (1972). The anticipated changes in the turbidity, temperatures, and volume of discharge of the Fraser River could all have significant effects.

One of the most productive areas of the Strait of Georgia is the Fraser River plume, which is formed as fresh water from the Fraser River flows out over the more saline waters of the Strait of Georgia. The differences in density result in vertical stability of the water column in the plume. In addition, as the fresh water flows over the deeper, nutrient-rich water there is an entrainment of the richer water into the surface waters. This stability and the relatively high nutrient concentration provide favorable conditions for the early initiation of spring phytoplankton blooms which provide the food for the zooplankton populations utilized by juvenile salmon on their arrival in the Strait of Georgia.

The increased flow of the Fraser from December–April following construction of a Moran-type dam would increase the areal extent of this

productive zone during the spring. The decreased turbidity of river water would lead to increased light penetration and thus contribute to a further enhancement of primary production. However, there is no guarantee that this enhanced production would be available to the zooplankton populations. The rate of development of zooplankton is affected by temperature which would be somewhat reduced in the plume during April and May. Parsons (1972) has suggested that the reduced temperatures in the plume in April and May would lead to slower development of zooplankton stocks. They might not be present in sufficient numbers to utilize the algal blooms as extensively as at present. A major portion of the primary production might then be available to benthic organisms. Any delay in the development of zooplankton could reduce the food available for young salmon. This, in turn, could lead to increased mortality during the early stages of marine existence.

Further increases in mortality might be expected as a consequence of the decreased turbidity in the plume. Parker (1968) has reported mortalities up to 77% for young pink salmon during their first 40 days in the marine environment. Decreased Fraser River plume turbidity could lead to an increase in visibility and therefore an increase in mortality due to predation. Assuming that Parker's value for pink salmon mortality applied to young salmon in the Fraser River plume, and assuming that the decrease in turbidity would increase early mortality by an additional 10%, then roughly 45% of the stock presently remaining at the end of 40 days would be lost. This hypothetical example indicates the possible major effects of a change in turbidity, a feature whose effects are usually not considered in evaluating the effects of hydroelectric developments.

Relationships observed by the International Pacific Salmon Fisheries Commission (Anon. 1971) lend support to the analysis of Parsons (1972). The percentage survival of both Chilko Lake yearling sockeye and Fraser River pink salmon are both associated with Fraser River discharge in a positive manner. This suggests that conditions in the Strait of Georgia are somehow influenced by discharge and that reduced discharge would lead to less favorable conditions for growth and/or survival. Cause and effect have not been demonstrated. However, the analyses of Parsons and the existence of the probability relationships described above suggest that the altered temperature, discharge, and turbidity regimes could significantly reduce the survival of young salmon. While spring primary productivity in the plume might be increased, it might not enhance zooplankton production. In addition, the reduced turbidity, while probably leading to an enhancement of primary production, could also increase predation on young salmon.

(b) *Fraser River* — The effects on the migrants or residents of the downstream changes resulting from a Moran-type dam have been reviewed by a number of workers (Anon. 1971; Andrew and Geen 1960; Geen 1972b). Flow, temperature, turbidity, and gas supersaturation changes could all have major effects on the salmonids in the river.

The reduced discharge during the summer could delay the initiation of the migration of adult salmon from the Strait of Georgia, into the Fraser River. Gilhousen (1960) demonstrated a significant relationship between Fraser River discharge and the duration of movement of Adams River sockeye into the Fraser River. It has been suggested (Anon. 1971) that a delay of several days might result from the lowered discharge in the Fraser River that would follow construction of a Moran-type dam. This might not be critical although late arrival of sockeye on spawning grounds can reduce egg survival if the eggs are exposed to relatively low temperatures early in development.

The reduction in downstream discharge during the April–May period could also adversely affect survival of young salmon moving seaward. Seaward migration occurs at a rate about equal to average river velocity and might extend the downstream migration by 2–3 days. In addition, the reduction in turbidity would likely limit daily migration to the darker hours, thereby extending the downstream migration periods even further than at present since some migration occurs in the turbid waters during daylight. There is some suggestion from Columbia River data that river mortality of young salmon is high and would presumably increase in the face of an increase in the time required to complete migration down the river.

Higher average winter discharges would be the case following construction of a Moran-type dam, thereby eliminating the winter low flows. This might enhance the survival of eggs in the river downstream from Hope. Although winter redd desiccation does not seem to be common in this area the increased flow would ensure better per-

colation through the gravel and presumably enhance egg and alevin survival (Geen 1972b).

Downstream temperatures would inevitably change if a Moran-type dam was constructed. The effects might be minimized by drawing water for the turbines from one or more depths so that river temperatures downstream match those that presently exist. However, it seems unlikely that a complete match would be possible and a lowering of temperatures in summer and an increase in the fall and winter relative to the present conditions would be expected. The summer temperature decrease would reduce the speed of upstream migration of adult salmon. It is not known if this could be critical.

The increase in fall temperatures downstream from the proposed Moran Dam could also affect the ultimate spawning success of pink and chum salmon that spawn in the Fraser River below Hope. It has been indicated that relatively high temperatures are associated with poor returning runs (International Pacific Salmon Fisheries Commission 1968). Precise reasons for this are yet to be established. However, the increased temperature would increase the rate of development and presumably lead to premature fry emergence and seaward migration. Arrival in the marine environment might precede the development of the abundant zooplankton food in the Strait of Georgia. Increased mortality would likely ensue. Available data certainly provide reason to be concerned about the biological consequences of any change in the winter temperature regime.

The effects of the reduction in turbidity below a Moran-type dam on conditions in the Strait of Georgia and on predation and rate of mortality of young salmon in the Fraser River have already been referred to. An additional consequence might be a gradual reduction in the percentage of fine material in the spawning areas. This could lead to improved percolation through the gravel and would probably improve survival of eggs in the gravel.

Construction of a Moran-type dam would probably result in supersaturation of downstream river water with dissolved gases, of which nitrogen would be of greatest concern. It has become increasingly apparent over the last decade that nitrogen supersaturation leads to injury and mortality of both adult and young salmon (Harvey 1967; Harvey and Cooper 1962; Ebel 1969; Beiningen and Ebel 1970 as examples). Water supersaturated with nitrogen is common in stratified lakes in summer and is the result of heating occurring to greater depths than wind mixing and air equilibration. In addition, supersaturation often results from entrainment of air into the water spilling from a reservoir. When water enters the plunge basin, the air is forced into solution and supersaturation results. Both reservoir and spillway supersaturation could be expected at Moran Dam. It would, as shown on the Columbia River, have a serious impact on young and adult salmon below the dam.

It is not known how far downstream supersaturation would persist. Data from the Columbia suggest that it is many miles. Beiningen and Ebel (1970) report a drop from 135 to 114% between John Day and McNary Dams, a distance of 120 km. As would be expected, more rapid equilibration occurs in turbulent water. It seems likely that supersaturation would persist downstream to at least Seton Creek and could therefore influence pink and sockeye destined for the streams of that system.

The effects might be felt as far downstream as the confluence of the Thompson and Fraser rivers although this is an additional 80 km below Seton Creek. Thus, it is uncertain whether nitrogen supersaturation would affect the large stocks of fish that migrate into the Thompson River system. However, there is no doubt that it would have very serious consequences for young or adult salmonids in the river immediately below the proposed Moran Dam. The effects of nitrogen supersaturation are reviewed in greater detail by Geen (1972b) and Anon. (1971).

Upstream Passage of Adult Salmon

If a Moran-type dam were constructed biologists would face major problems in moving adult salmon over the dam. It has been estimated that a maximum of 750,000 adult salmon/day could require passage over the dam during the peak of upstream migration (Anon. 1971) if all rearing areas upstream of Moran Canyon were fully utilized. The details of the various methods that might be used for upstream transport have been thoroughly reviewed by Andrew and Geen (1960), Geen (1972a), and Anon. (1971). Any collection and transport system would have to operate efficiently to minimize delay of migrating adult sockeye. It is well documented that delay in spawning migration results in reduced spawning efficiency and in extreme cases, failure to reach the spawning grounds. This is related to the finite energy stores that adult sockeye possess. Once they enter fresh water they cease feeding and exist on stored energy. Idler and Clemens

(1959) have shown that the stores are just sufficient to permit completion of spawning. A delay of even a few days can result in a major decrease in spawning efficiency.

Two main systems might be imagined as means of coping with the upstream migrants:

1. Transport of fish over the downstream reregulating dam, upstream migration to Moran Dam, attraction of fish at Moran Dam by powerhouse or spillway collection facilities followed by transport over Moran Dam by means of fishways, fish locks, or mechanically. This would be followed by the migration of the adult salmon through the reservoir above Moran Dam.

This system would involve construction of collection and passage facilities at both Moran Dam and the reregulating dam. Some delay would be expected below both dams. The magnitude of the passage and collection facilities, whether fishways, fish locks, or mechanical, which would be required is unprecedented.

The possibility of success in any attempts to handle adult fish should not be regarded optimistically. A delay of 2 days at each dam is a moderate estimate. Additional delay of adults could be expected in the reservoir. In any event, the total delay would be significant. The cumulative effects of delay would likely be such that a significant fraction of the spawners would never reach their spawning grounds and the remainder would spawn with reduced effectiveness. Evidence is also accumulating from the Columbia River which indicates that many adult salmon never find their way through reservoirs. It may be that straying and nitrogen supersaturation all contribute to this loss.

2. The second likely system would involve collection of adults below the reregulating dam and transport by truck to the head of the reservoir some 325 km upstream. Delay would thus be minimized. However, biological and economic problems would exist. Mortality of fish transported by truck is common although it is by no means certain to what extent this would apply to sockeye. Some physical injury and stress would be expected. In addition the cost of truck transport would be very high. It has been estimated (Anon. 1971) that a capital cost of $40 million would be required for the 675 trucks necessary to haul the maximum daily anticipated numbers of adult sockeye. Loading and unloading facilities would require an extra expenditure. Even with the runs of the present size, capital costs could be $15–20 million. Depreciation and operating costs of this transport system would comprise a significant fraction of the present landed value of the commercial catch of fish from stocks originating above Moran Dam.

In conclusion, the prospects for safe and economically defensible means of transporting adult-sockeye over Moran Dam are minimal. It is this which has led many to suggest that insofar as a high-head Moran-type dam is concerned, it is either fish or dams. The two could not coexist, at least over the long term.

Downstream Migration and Passage of Young Salmon

Any salmon that did get over a dam and through the reservoir to their spawning grounds without undue delay would produce young which would face a multitude of perils in the course of seaward migration.

A delay in the reservoir during downstream migration is to be expected. It has been estimated (Anon. 1971) that migration time through the Moran Reservoir would be increased 11–25 days, depending on river discharge and reservoir length. Predation and residualism would probably lead to losses of 25–85% of the downstream migrants (Anon. 1971). Hamilton et al. (1970) concluded that predation in Lake Merwin, a Washington State hydroelectric reservoir, resulted in high mortality of young coho salmon. Attempts to minimize predation by the removal of predators were unsuccessful.

Delay of young of at least some species of salmon, including sockeye, may result in large numbers becoming residual in large reservoirs. It seems that any major delay in downstream migration leads to a loss in the migratory tendency of the young salmon which is indicative of physiological changes. The delayed fish may migrate the following year or simply remain in the reservoir where they could support a sports fishery which would not match the commercial value of the same fish had they gone to sea.

It would obviously be desirable to avoid delaying young salmon in the reservoir. With this in mind considerable attention has been devoted to methods of collecting young salmon, both in the forebay of the dam and in the river immediately above the reservoir.

Several of the attempts to collect migrants from rivers at the upper end of reservoirs have been described by Andrew and Geen (1960) and Anon. (1971). These have involved use of louvers or vertical travelling screens. Louvers have not proven particularly satisfactory and their use has

largely been discontinued. Nor do travelling screens seem particularly likely to be successful in the Fraser River. The total volume of river water would have to be strained and fish separated from debris. Ice would be a major problem during the period of downstream migration. Supposing that such collection methods did work, it would still be necessary to develop systems for transport below the dam, something which seems possible though without precedent in terms of the numbers and distance involved (Geen 1972a).

In the absence of a river collection system, young salmon would move into the reservoir. Some would eventually arrive at the dam. Either they would be collected in the forebay, and be transported over the dam, or pass through the turbines or over the spillway. Large-scale collection of young in a forebay has never been successful and there is little reason to expect that fixed or moving screens or any of the artificial outlets known as "skimmers" or "gulpers" would be satisfactory. Such successes as these techniques have enjoyed have been confined to relatively small reservoirs where small populations of downstream migrants are involved.

The inability to collect a significant fraction of the young salmon would mean that they would sound and go through the turbines, pass over the spillway, or remain in the reservoir. Considerable mortality usually results when young salmon pass over a spillway or through turbines. The details are reviewed by Andrew and Geen (1960) and Anon. (1971). The spillway could be designed to minimize mortality, although the requirements for energy dissipation and minimal nitrogen supersaturation might not be compatible with design for minimum fish mortality. An unknown fraction of the young salmon would go through the turbines, particularly in the early spring before the reservoir reached spilling elevation. A 50% mortality of those going through the turbines could be expected (Geen 1972a).

It seems likely that the salmon stocks could not be maintained given the systems available for collection and transport of fish, both upstream and downstream. The expected delays and mortalities would inevitably result in a reduction of the stocks, even given conscientious and expensive effort to maintain them.

This realization has given rise to suggestions in some quarters that the stocks should be maintained artificially, usually by hatcheries. The value of various alternatives to natural production has been examined by Andrew and Geen (1960), Clay and Larkin (1959), Smith (1960), Anon. (1971), and Geen (1972c). There is general agreement that the alternatives to natural production would not maintain some stocks but could supplement the natural production of others.

For many years there have been attempts to supplement natural production in a variety of ways. Hatcheries and artificial spawning channels are often employed for this purpose. Many efforts of this type are currently taking place in the absence of hydroelectric development and in areas unaffected by the proposed Moran Dam. Developments of this sort which might enhance downstream production should not be viewed as an alternative to natural upstream production since they can be initiated in appropriate areas as funds and technology become available. For purposes of this discussion the alternatives to be considered are those methods that might be employed to maintain stocks of salmon and trout originating upstream from the site of the proposed Moran Dam.

The principal problems would be encountered with sockeye salmon by virtue of both their numbers and biological characteristics. However, many of the biological problems would also be common to chinooks and steelhead trout. In general, fish of these three species would reach Moran Canyon from 2 wk to several months before spawning. Thus, pools in which fish could be held to maturity would be required. Once the fish reached maturity either artificial spawning channels or hatcheries would be required to handle the eggs. On hatching, rearing ponds would be required in which the young could be fed and maintained until they were ready to migrate seaward. On first glance this might appear as a gigantic though feasible task. However, closer analysis suggests that this is not so. In several cases sockeye would arrive at Moran Canyon a month or more in advance of spawning. They would have to be held until mature. This might lead to considerable egg mortality. Foerster (1938) reported a loss of 22.8% of the eggs associated with the retention and handling of sockeye salmon in Sweltzer Creek, the outlet of Cultus Lake. These fish were collected near their spawning grounds. Fish collected a considerable distance from the spawning grounds might suffer higher mortality.

Once fish reached maturity there should be little biological problem presented in the fish utilizing artificial spawning grounds or the eggs being maintained in hatcheries. However, once the fry hatched it would be necessary to maintain them in rearing ponds on artificial food. There is

no evidence to indicate that a rearing pond represents a satisfactory alternative to the large, oligotrophic lakes in which young sockeye normally spend their first year. Several attempts to rear young sockeye in large pools have enjoyed very limited success. These attempts have been marked by epidemic disease and a great sensitivity to nutrition (Anon. 1971).

Thus, there is little evidence to suggest that sockeye stocks upstream from Moran Canyon could be maintained by hatcheries or artificial spawning channels. The problems associated with holding adults to maturity and rearing the young are such that success is unlikely. In addition, the costs of such alternatives to natural production are prohibitive even if success were guaranteed. Smith (1960) estimated the costs which might be involved in the hatchery production of sockeye. Using his estimates of costs, the production of 7.8 million sockeye would require capital expenditures of $206 million, and $27 million for annual operating or about 1.5 times the annual landed value of the fish produced. The magnitude of the physical plant required is large. Using average survival estimates, Smith (1960) estimated that 3.45×10^9 sockeye eggs would be required to produce 19×10^6 adults (the size of the 1958 Adams River sockeye run). These would require 34,500 egg-incubation cabinets, over 93,000 m^2 of covered hatchery space, 3,600 (149-m^2) rearing ponds, and a total flow of 380 m^3/s. Smith's estimates were derived from accepted hatchery design criteria. It has been estimated that the cost of facilities of chinook rearing and incubation would be an additional $5.4 million with an annual operating cost of $700,000. These cost estimates are based on potential production of salmon populations upstream of Moran Canyon, which is substantially above present production levels. However, the calculations still serve to indicate that maintenance of the stocks would not be an economically viable proposition.

There seems to be no other conclusion but that a high-head dam at Moran Canyon would eliminate upstream salmon and steelhead populations and could lead to a decrease of the size of downstream stocks as well. Satisfactory methods for transporting large numbers of young and adults over a dam do not presently exist in spite of considerable efforts to develop the appropriate systems. Alternatives to natural production do not seem viable either biologically or economically. The choice is clearly between upstream salmon stocks or dams. An area requiring much more study would seem to center on downstream effects of a high-head development on the Fraser River. Many of the changes that would occur could be expected to have profound effects downstream, although sufficient basic data are not available to make definite statements at this time.

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Development of James Bay: the Role of Environmental Impact Assessment in Determining the Legal Right to an Interlocutory Injunction[1]

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PENN, A. F. 1975. Development of James Bay: the role of environmental impact assessment in determining the legal right to an interlocutory injunction. J. Fish. Res. Board Can. 32: 136–160.

This paper examines the nature of the interlocutory injunction sought by Indians in the James Bay Territory to halt development by the James Bay Development Corporation (JBDC), especially the legal requirement that the Petitioners demonstrate "serious or irreparable injury" arising from the project, and that they are and will continue to be adversely affected by the project.

Demonstration of injury and adverse effects required carefully argued environmental impact assessment. These impact assessments relate chiefly to changes in hydrology, vegetation, fisheries, and mammalian ecology and, in that the assessments constitute important evidence for determining rights to the continued enjoyment of the resources of a region, their significance extends beyond the immediate claim for recognition of Indian title to land.

As long as criteria do not exist for establishing the content of impact assessment or for determining the action to be taken on the basis of such assessment, it is considered unrealistic to require an overall impact assessment that could withstand careful scrutiny of both the general public and of environmental scientists. It appears more reasonable to require a developer to identify specific environmental problems that are likely to arise from conflicting uses of the natural resources of a region. The research should be commissioned and the conclusions should be submitted, with engineering plans, for approval to a specially designated authority. Such procedure is necessary to avoid costly and time-consuming court hearings.

Environmental scientists must be explicit in explaining what they are able to predict with confidence, what could be predicted with additional research, and what can never be satisfactorily predicted, regardless of the amount of research conducted. Experience in the James Bay case indicates that scientists frequently do not provide clear statements about the likelihood of certain impacts or about the difficulty in the prediction of some kinds of impact.

PENN, A. F. 1975. Development of James Bay: the role of environmental impact assessment in determining the legal right to an interlocutory injunction. J. Fish. Res. Board Can. 32: 136–160.

Cet article examine la nature de l'injonction interlocutoire demandée par les Indiens du territoire de la baie James dans le but d'arrêter les travaux de la Société de développement de la baie James (SDBJ). Il examine plus particulièrement l'exigence légale voulant que les requérants démontrent les « dommages sérieux et irréparables » causés par le projet et prouvent que ce dernier continuera de les affecter défavorablement.

Une preuve de dommages et d'effets défavorables a exigé une évaluation soigneusement présentée de l'impact environnemental. Cette évaluation porte surtout sur les changements de conditions hydrologiques, de végétation, de pêche et d'écologie des mammifères. De plus, comme ces évaluations constituent un facteur important lorsqu'il s'agit de déterminer les droits à la jouissance continue des ressources d'une région, leur signification ont une portée plus grande que la revendication immédiate du droit de propriété du terrain par les Indiens.

Aussi longtemps qu'on manquera de critères pour établir le contenu d'une évaluation d'impact ou pour régler la conduite à suivre sur la base d'une telle évaluation, il n'est pas réaliste d'exiger une évaluation d'impact qui tiendra devant l'examen critique tant du public en général que des scientifiques de l'environnement. Il semble plus raisonnable d'exiger qu'un promoteur

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identifie les problèmes environnementaux particuliers susceptibles de surgir lorsqu'on fait des ressources naturelles d'une région des usages contradictoires. La recherche devrait être effectuée à forfait, et les conclusions soumises, avec plans et devis d'ingénieurs, à une autorité spécialement désignée. Une telle procédure est nécessaire si l'on veut éviter des procédures judiciaires longues et coûteuses.

Les scientifiques de l'environnement doivent fairre ressortir clairement ce qu'ils peuvent prédire avec confiance, ce qui pourrait être prédit à la suite de recherches plus poussées et ce qui ne peut jamais être prédit de façon satisfaisante, quelle que soit le volume de recherches effectuées. Le cas de la baie James indique que, souvent, les scientifiques ne se prononcent pas clairement sur la probabilité de certains effets ou sur la difficulté de prédire certains genres d'impact.

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Preface

This paper was prepared when the petition of the Indian and Inuit peoples seeking an interlocutory injunction against the James Bay Development Corporation was still under advisement. The importance which the judge presiding over the case would attach to environmental impact testimony was therefore unknown.

The decision to grant an interlocutory injunction, which was announced on November 15, is discussed in the Appendix.

In the belief that this paper required an analysis of the environmental impact evidence used in the court hearings, I have attempted to assess the significance of the different types of impact evidence that were produced. This analysis is based on documents submitted as evidence in court, transcripts of testimony by expert witnesses, summaries of the case prepared by both Petitioners and Respondents, personal communication with individuals directly involved in the case, and my own experience of the subject matter. Although conclusions put forward in this paper are necessarily my own, it is hoped that they are reasonably securely based on fact.

THE James Bay development is an ambitious program of development of the lands bordering the eastern shore of James Bay, based on the harnessing of some 13,000 MW of hydroelectric power from major rivers in the region. The territory involved in the development is defined in the 1971 James Bay Development Act as being bound "to the west by the west boundary of the Province of Quebec, to the south by the parallel of latitude 49°00′N, to the east by the electoral districts of Roberval, Dubuc, and Saguenay and by the extension northerly of the west boundary of the electoral district of Saguenay and to the north by the parallel of latitude 55°00′N." In this paper the word "territory," unless otherwise stated, refers to this definition.

Quebec has invested heavily in hydroelectric power. In 1970 it produced 47% of Canada's hydro power, compared with 5.2% of the nation's thermal generating capacity. The total amount of power made available by the development of James Bay will approximately double the existing installed hydro generating capacity in the Province (13,250 MV in 1970). The northern section of the development, which is the subject of this paper, will itself generate some 8,300 MW at installed capacity.

The development of James Bay has aroused considerable public attention over the last year for three principal reasons. First, the native peoples in the regions affected by the development (about 6000 in number) are seeking an interlocutory and then a final injunction to halt the development. Secondly, the development has taken on a direct political significance as a result of the personal involvement of Premier Bourassa in the project, the amount of capital investment involved (between 7 and 10 billion), and the additional employment that will be created during the construction phase of the project. Thirdly, there was at the time of Premier Bourassa's announcement of the project a widespread feeling that inadequate attention had been paid to the question of environmental impact assessment. The subsequent appearance of a report on environmental impact prepared by a joint Federal–Provincial Task Force in December 1971, which emphasizes the difficulties that would face native peoples in the region, the lack of background information in the region, and the short time allocated to the Task Force to complete its report, enhanced this impression.

This paper deals with environmental impact assessment in the context of the court hearings

held to determine whether an interlocutory order of injunction should be issued to provide a temporary halt to the development. The object of the paper is to examine the circumstances in which environmental impact evidence has been used in the court hearings, and to consider the role, both actual and potential, of environmental scientists in formulating and presenting impact assessments pertinent to a project of this kind. Emphasis is placed on the hearings for an interlocutory injunction because almost all of the environmental impact research that has been carried out in connection with the James Bay program has been used, in one way or another, to determine whether the rights of native peoples in the development territory are being threatened to the extent that the legal remedy of injunctive relief is necessary to safeguard these rights. The legal principles which involve the application of environmental impact testimony have a significance which extends far beyond the immediate court hearings and the determination and protection of Indian title to land; these principles, as will be discussed later, are relevant in determining the role of the environmental scientist in impact assessment.

At the outset, it is necessary to provide working definitions for certain terms which can lead to ambiguity. "Environment" is defined (according to Webster's dictionary) as "the aggregate to all the external conditions and influences affecting the life and development of an organism," and this definition is intended to be as wide-ranging as possible. "Environmental impact" includes all physical, chemical, and biological changes of air, land, or water which affect human life and species of plants and animals useful to man (inclusion of the latter phrase reflects the fact that we are concerned here with impact assessment as it relates to the determination of whether rights to the enjoyment of the natural resources of a region are being violated). "Environmental impact assessment" refers to any reasoned evaluation of any of the changes mentioned above, whether the changes have taken place or whether they are anticipated.

We begin with an account of the evolution of the James Bay Development Corporation (JBDC), the organization which is responsible for the development of the James Bay territory. The development of the La Grande drainage basin and its adjacent catchments, the first major stage in the overall development program is then described in some detail. We then examine the nature of the proceedings for an interlocutory injunction against the JBDC, concentrating in turn on the disputed rights of the native peoples and the conditions which must be satisfied for an injunction to be granted — particularly the demonstration of "serious or irreparable injury" to the Petitioners. This leads to a discussion of environmental research and testimony introduced in court to show or disprove "serious or irreparable injury" arising from environmental damages. The experience gained as a result of the James Bay hearings is then discussed, and the significance of these hearings is considered in defining the roles and responsibilities of environmental scientists in environmental impact assessment.

Evolution of the James Bay Development Corporation

A number of gauging stations were established on the major rivers of northern Quebec in 1960 and 1961 by the Quebec Ministry of Natural Resources. Preliminary evaluations of the hydroelectric potential of the regime were made in 1964, at about the same time that Hydro-Quebec became a publicly owned energy corporation. Little more was heard about the subject until November 1970, when Hydro-Quebec issued parallel mandates to two groups of consulting engineers to investigate the feasibility of developing the main rivers draining into James Bay from Quebec — the Nottaway, Broadback, Rupert, Eastmain, and La Grande rivers. The mandate required the consultants "to advise the [Hydro-Quebec] commission as soon as possible so as to establish a general practical and economical concept for the development of the hydroelectric potential of the James Bay region."

The reports were submitted in March 1971. Both groups of consultants advised that the development was indeed feasible and that between 12 and 15,000 MW of power could be generated from an investment of about $7 billion. One group (Asselin et al.) advised that the Nottaway, Broadback, and Rupert basins be developed first. The other group (Rousseau et al. 1972) advocated the development of the La Grande River basin as the first stage in the program. Six weeks later, Premier Bourassa announced to the Liberal Party his decision to commence the development of hydroelectric power in the James Bay region.

Rousseau et al. (1972) then, in June 1971, received a mandate from Hydro-Quebec "for the collection of data, conceptual studies, and the preparation of a definitive report on the development of the hydro-electric potential of the La

Grande river catchment area, including possible diversions from adjacent drainage areas." The report was submitted in January 1972 and was the basis for a publicity document outlining the development issued by the JBDC in May 1972. It was now apparent that development of the La Grande River basin, and probably also of its adjacent catchment areas, would proceed, and that exploitation of the Nottaway, Broadback, and Rupert river systems would follow later.

In July 1971, shortly after Premier Bourassa's decision to develop the James Bay region, the James Bay Region Development Act was passed by the National Assembly of Quebec, establishing the James Bay Development Corporation as a joint stock company (and as a Crown Corporation) with the task of promoting "the development and exploitation of the natural resources in the Territory." The Act, apparently an attempt to divest Hydro-Quebec of some of its rapidly increasing power, was a source of political controversy in the summer of 1971. As a result, the JBDC established a subsidiary James Bay Energy Corporation (JBEC), with 51% of the shares held by Hydro-Quebec and 40% by the JBDC. All electricity generated would be sold by the JBDC to Hydro-Quebec. Subsidiaries were also created for the exploitation of petroleum, forestry, and mining resources, with the JBDC holding 51% of the shares. Further rivalry between the JBDC and Hydro-Quebec followed in 1972. Both the Provincial Government and the JBDC intended to entrust management of the JBDC to a consortium of private firms, but eventually Hydro-Quebec took over the management itself.

The JBDC has far-reaching powers under the Development Act. The Territory was declared a municipality, with the JBDC acting as the municipal council, which gave the JBDC the right to declare communities of 500 or more persons a "locality," establish a local council, and appoint five members to it. The JBDC has extensive powers of expropriation and control over rights related to other Acts governing mines, river power, fisheries, forests, agriculture, and tourism. Several Acts which might be involved in environmental litigation are specified in the Development Act and specifically excluded from having authority over the JBDC, and there is an explicit provision that the "application of laws respecting mines, hydraulic resources, fish, game, agriculture, colonization, or tourism" shall be consistent with the aims of the Development Act, namely, those of "promoting the development and exploitation of the territory.'

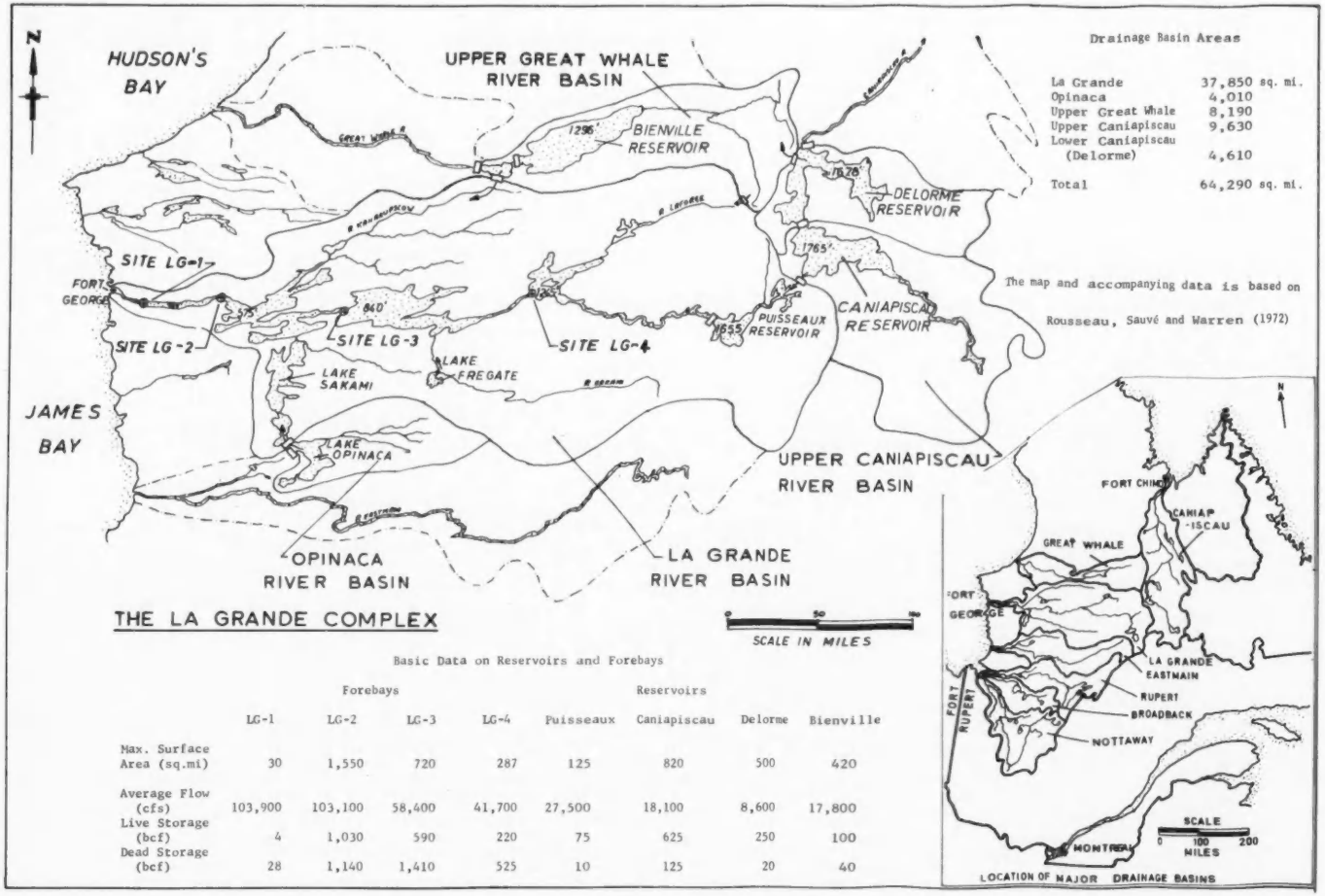
The Development Act also contains clauses relating to environmental protection and respect for Indian rights: (5) "The Corporation must see to the protection of the natural environment and prevent pollution in the Territory," and (43) "This Act shall in no way affect rights of the Indian communities living in the area."

The preceding brief review is intended to show how the publicly owned power utility of Hydro-Quebec has received extensive administrative powers over some 130,000 square miles of Quebec, which enables it to control not only the development of hydroelectric power but also the development and exploitation of many other natural resources of the region.

Description of the La Grande Complex Development

The ultimate development of the hydroelectric potential of the James Bay Territory involves the harnessing of the catchments of the Nottaway, Broadback, Rupert, Eastmain, and La Grande rivers. In this paper we are chiefly concerned with the La Grande basin, because it will be the first basin to be developed and because it is the subject of the interlocutory injunction hearings. This section describes the program of development for the scheme known as the La Grande Complex, which is an extension of the development of the La Grande basin involving diversions into the basin from parts of the catchments of the adjacent basins of the Eastmain, Caniapiscau, and Great Whale rivers. The inclusion of diversions is, according to engineering reports, economically more attractive than the development of the La Grande alone. Although it is still not absolutely clear what diversions will be utilized in the final development, scientists working on environmental aspects of the development have assumed that diversions will be included and have considered environmental impact in the adjacent catchments which will experience major reduction of flows in rivers. A map of the La Grande Complex is shown in Fig. 1.

The first factor to be appreciated is one of scale. The area of the La Grande catchment alone is about 38,000 square miles, about 29% of the 130,000 square miles of the James Bay Territory. The latter area is nearly one-third of the area of Quebec, and is equivalent to the area of France. If adjacent catchments affected by diversions are included, the total area involved in the La Grande Complex is nearly 60,000 square miles. The Territory as a whole supports a native population of



THE LA GRANDE COMPLEX

Basic Data on Reservoirs and Forebays

	Forebays				Reservoirs			
	LG-1	LG-2	LG-3	LG-4	Puisseaux	Caniapiscau	Delorme	Bienville
Max. Surface Area (sq.mi)	30	1,550	720	287	125	820	500	420
Average Flow (cfs)	103,900	103,100	58,400	41,700	27,500	18,100	8,600	17,800
Live Storage (bcf)	4	1,030	590	220	75	625	250	100
Dead Storage (bcf)	28	1,140	1,410	525	10	125	20	40

FIG. 1. The La Grande Complex.

about 5,500, of which 600 are Eskimo and the remainder Cree Indians. The Indian population is nearer 8,000 if peoples not living in fixed settlements are included. The native population in the La Grande Complex region is in the order of 2,500. The majority of the Cree in the Territory have a subsistence economy and depend on wild animals as a source of protein. The James Bay region as a whole is the "empty quarter" of Quebec, and access from the south has been limited to roads leading to the mining and paper pulp towns of Matagami, Quevillon, and Chibougamou, the rail head at Matagami, and a number of air strips. In recent years, hunting and fishing camps have been established near Lake Mistassini and in the upper part of the Caniapiscau basin, to which the only access is by air. The principal fixed settlement of interest in the case of the La Grande development is the community of some 1,300 Indians and 100 Eskimo at Fort George, which is situated on an island in the estuary of the La Grande River.

The principal attractions of the La Grande Complex, from the point of view of hydroelectric power development, were threefold. First, there is a single site where 500 ft of head can be developed from one generating plant (LG-2, discussed below), and construction of this plant would enable the Development Corporation to meet Hydro-Quebec's requirement that units with a minimum capacity of 2,000 MW be installed and in service in the winter of 1977–78. Second, the installed capacity of the development could be substantially increased and the unit cost of the power reduced by diverting flow from adjacent river basins through the La Grande river system. Third, the La Grande basin is more sparsely populated than the basins to the south, and on this basis it appeared that this development would have less affect on indigenous peoples.

Before proceeding to the description of the La Grande Complex, it may be useful to review briefly the main physical characteristics of the region. The La Grande and the adjacent Eastmain, Caniapiscau, and Great Whale rivers drain the interior plateau lands of central Quebec. This land is underlain by an Archean basement complex of granites, gneisses, gabbros, and metasediments which was heavily glaciated during the Pleistocene period. The interior plateau ranges in altitude from 1,500 to 2,000 ft, with local relief of only a few hundred feet. The area is characterized by a very complicated network of lakes which comprise between 10 and 25% of the surface area, depending on the region. Surficial deposits of glacial origin are widespread, with eskers and drumlin fields forming a distinctive feature of the land as seen from the air. The longitudinal profiles of rivers in this region exhibit rock-controlled breaks in slope (knick points) which make them particularly suitable for hydro development. Towards the coast of Hudson's and James Bay, marine and estuarine (brackish water) silts and clays of late-Quaternary age extend inland about 70 miles at the latitude of Fort George and reach a maximum elevation of some 800 ft.

Knowledge of the climate is based on AES stations at Moosonee, Chapais, Port Harrison, Nitchequon, and Schefferville. All these stations lie outside the La Grande basin. The 25 and 32° mean annual isotherms pass across the north and south of the territory, and mean July and January temperatures for the north and south of the territory, respectively, are about 55 and −10°F, and 65 and 5°F. In the La Grande district, mean annual precipitation is about 40 inches (if allowance is made for gauging error) and rather more than half this quantity is received as snow. Snow cover in the La Grande basin persists from mid-October until mid-May, although the timing is markedly dependent on latitude and elevation. The median depth of the snowpack in early April ranges from 20 to 40 inches or more between the coast and interior plateau. Summer rainfall is characteristically of long duration and low intensity, such that the 10-yr return period, 24-h rainfall (generally based on about 25 yr of record) is about 2.5 inches in the center of the territory. Ice forms on the lakes between early November and early December, and breaks up again between late April and early June. The timing of ice formation and breakup on the same lake varies over a span of 2 or 3 wk from year to year. The breakup of river ice is closely tied to snow-melt runoff in spring, and is probably more generally predictable than lake ice breakup. Ice thicknesses on the lakes are usually in the order of 3 ft 6 inches. Ice thickness and extent and the depth of the snowpack are important controls on the movement of large mammals in the region. In addition, the amount of snow accumulation on lake ice is important in determining its trafficability and the volume of low (river) flow during the late winter.

The vegetation of the territory, which is discussed in more detail later, can perhaps be described very simply as a combination of three vegetation communities which grade continuously into one another (Hare 1959): closed-canopy coniferous forest consisting mainly of spruce, with a forest floor composed mainly of mosses (closed-canopy here means continuous forest, as

spruce does not form a continuous canopy because of its conical form); open lichen woodland, consisting of scattered spruce and a ground cover of lichen and a secondary shrub community of alder and willow; and wetland vegetation communities, which include muskeg, moist tamarack woodland, and especially the relatively productive shrub-land of lake shores and river banks with its diverse herbaceous layer. Closed-canopy woodland is largely confined to sheltered valleys at low elevations and near watercourses, whereas the open lichen woodland becomes dominant towards the interior of the territory. Very little of the woodland contains merchantable timber. That part of the fauna associated with these plant communities which is of most direct importance to the Indian economy consists of beaver, woodland caribou, fox, rabbit and hare, ptarmigan, duck, and geese. Whitefish, brook and lake trout, and to a lesser extent sturgeon and land-locked salmon are the species of fish chiefly used by the Indians.

The La Grande Complex

The basic strategy of the La Grande Complex is to develop 1245 ft of head in the La Grande River between 10 and 1255 ft A.S.L. using a set of four major dams at distances of 23, 78, 148, and 288 miles upstream from the estuary of the La Grande at Fort George, taking advantage of constrictions and breaks of slope in the La Grande valley. By developing almost the entire head of the river over this distance, a total of 8330 MW can be generated at installed capacity. The dams are best known as sites LG-1, LG-2, LG-3, and LG-4, in order of increasing distance from Fort George, and they will be referred to in this paper by these abbreviations. The impoundments immediately behind these dams are known as forebays, distinguishing them from the reservoirs which will provide long-term regulation of flows to the forebays. One of these reservoirs, the Puisseaux reservoir, will be located in the headwaters of the La Grande basin. In the La Grande Complex scheme, four additional reservoirs will be created in adjacent basins to provide augmented flow through the La Grande River system. The Bienville reservoir located in the headwater of the Great Whale River will store water to be diverted down the Kanaaupscow River towards the LG-2 forebay. In the headwaters of the Caniapiscau River basin, which flows north to enter Ungava Bay at Fort Chimo, two reservoirs will be created: the Caniapiscau in the extreme headwaters of the basin, and the Delorme immediately downstream from the Caniapiscau. Flow from the Caniapiscau reservoir will pass directly to the Puisseaux reservoir, whereas flow from the Delorme reservoir will be diverted through the Bienville system towards LG-2. There is a possibility that the Delorme and Caniapiscau reservoirs will be combined to form one large reservoir, in which case most of the flow from this system would pass to the Puisseaux reservoir. Associated with the reservoirs are control structures and spillways which can be used to divert excess storage down the Caniapiscau and Great Whale rivers. On the south side of the La Grande, flow from the Sakami River, which now flows into the La Grande through Lake Sakami and so would normally enter the LG-2 forebay, will be diverted through Fregate Lake to pass through the LG-3 forebay and thence to LG-2. Finally, flow in the Opinaca River basin, presently tributary to the Eastmain river, will be diverted through Lake Sakami towards LG-2. Details of these diversions may be found in Fig. 1, which includes basic data on the different impoundments.

It is evident that the proposed diversions and the regulation of flows will produce a fundamental change in the flow regime of the La Grande between LG-1 and the estuary of the river at Fort George. In effect, the mean annual flow of the La Grande at Fort George will increase from 61,000 cfs at present to 104,000 cfs after completion of the La Grande Complex. Meanwhile, the mean annual flood at Fort George will be reduced from 152,000 cfs to about 120,000 cfs and, correspondingly, extreme flows will also be substantially reduced, except in the case of major release of flow through the spillway systems.

Description of Individual Impoundments

LG-1 — The first power plant, 23 miles upstream from Fort George, will provide 920 MW at installed capacity when it is brought into operation in 1982, as the last major power unit of the La Grande development. An earth and rock-fill embankment will be constructed at a point where the river flows over a granite outcrop, and will enable a head of 93 ft to be developed between the regulated impoundment level and the tailwater elevation of 12 ft. Both the powerhouse and the spillway will be constructed on the river bed at the site of the existing rapids. The powerhouse will contain eight units, each rated at 115 MW. The embankment will require 3.5 million yd^3 of fill and will be constructed, in part, on marine clays which reach a depth of 140 ft immediately north of the river. The fill will be obtained from

local outcrops of marine clay, till, and alluvial terraces.

The impoundment will extend 50 miles upstream and will flood the existing river banks, which consist of unconsolidated silts and clays and which are presently prone to slippage. In engineering reports, it is stated that the operating range of water level should be kept to within 5 ft to minimize bank erosion. It appears that the impoundment will be about 1 mile wide over most of its length, approximately double the width of the present river. The average depth at maximum level is estimated to be 38 ft. Flooding of river banks in this section will result in flooding of an important source of wild food habitat for the Fort George community.

LG-2 — The dam site 78 miles upstream from Fort George is the major power plant for the La Grande development and, at installed capacity, will generate 4410 MW from nine units, each of 490 MW; this is about 53% of the total generating capacity for the La Grande Complex. The river at this point is entrenched into a granitic massif, forming a valley in which a concrete-faced, rock-fill dam will be built with a maximum height of 493 ft and a crest width of 7600 ft. The 23.6 million yd^3 of rockfill required for the dam will be obtained from quarries near the dam site.

The power station will be built underground at a site 3 miles downstream from the dam, taking advantage of a natural valley which runs south of and parallel to the main river. The westward extension of this valley will serve as a spillway, so that flow down the spillway will return to the river some 12 miles downstream from the dam. Two diversion tunnels, with a total capacity of 220,000 cfs, will carry flow during the dry phase of construction. The capacity of the spillway will be 360,000 cfs, and there is provision for additional channels for emergency releases of water.

The maximum area of the impoundment created by LG-2 will be 1540 square miles. Using a figure of 30 ft for the operating range and the storage-forebay elevation curves provided in engineering reports, the minimum area of the impoundment could be as low as 900 square miles, which would indicate that an area of some 600 square miles might be exposed during drawdown. Over half the impoundment area, it appears, will be less than 50 ft deep, even at maximum water level, from which it seems likely that the closed-canopy and open woodland presently in the area will stand above water level. Presently, the water surface area in the impoundment is between 10 and 15% of the total area.

LG-3 — The dam site LG-3, 148 miles upstream from Fort George, takes advantage of a bedrock island in the center of the river. The completed dam will be 9700 ft long, 293 ft high, and will consist of sand and gravel with a central till core, requiring 23 million yd^3 of materials from local till and sand deposits. The power station will be sited on the island, and will provide a total capacity of 1500 MW from five 300-MW units. Till occupies 40% of the dam site, and provision has been made for excavation of this till to bedrock, although seismic surveys suggest this may not be necessary. The spillway will be located 3 miles south of the dam, and flow through the spillway will return to the river 5 miles downstream. The tailwater level (the water level where flow emerges from the turbines) will be continuous with the LG-2 forebay, and will vary with the amount of flow from LG-3 as well as the level of the LG-2 forebay. LG-3 is scheduled for completion after the construction of LG-2, with the constraint that the filling sequence will be delayed so that two units from LG-2 can be brought into operation by 1978.

The maximum forebay area for LG-3 will be 720 square miles, and at the maximum operating level the mean water depth will be about 85 ft. At the minimum operating level (30 ft below maximum) some 10 square miles of foreshore will be exposed. As in the other impoundments, a considerable amount of timber will stand above water level.

LG-4 — LG-4, at mile 288, will be a rock-fill embankment at 11,200 ft long and 408 ft high, and will provide four 375-MW units in an underground power station operating under a gross head of 400 ft. This dam will become operational between 1980 and 1982. The impoundment, which will drown a number of small hills, will have a maximum surface area of 287 square miles and a mean depth, at this area, of 67 ft. The spillway design is similar to that for LG-2 and LG-3, and as in the case of the other dams, the 48 million yd^3 of fill required for the dam and adjacent dykes will be obtained from nearby deposits of till and sand.

Diversions — An outline of the system of diversions has been presented; the only points raised here concern the extent and depth of the individual reservoirs. The Caniapiscau and Delorme reservoirs will have maximum and minimum areas face areas of 820 and 375 square miles, and of 500 and 80 square miles, respectively. Puisseaux reservoir will have miximum and minimum areas

of 125 and 25 square miles, while Bienville will have corresponding areas of 420 and 390 square miles. Mean depths at maximum and minimum storage levels range from 33 to 9 ft, except for Bienville, which is substantially shallower. Figures given in one of the environmental studies indicate that a combined Caniapiscau–Delorme reservoir would have a total water surface area of over 3000 square miles.

The impression created by these figures is that the reservoirs are uniformly very shallow and that most of their beds will be exposed at times of low storage. Most of the vegetation to be flooded in the reservoirs is open lichen woodland.

Cumulatively, the surface area data for the La Grande Complex indicate that about 4500 square miles will be under water, representing an increase in water surface area of 3400 square miles. The Delorme–Caniapiscau system would, if constructed, increase this value to as much as 5000 square miles. The increase in water surface amounts to 6 or 7% of the total catchment area of the La Grande Complex.

Miscellaneous services — Environmental studies conducted for Petitioners also considered the impact of other services, especially air strips and access roads to the development from the south. Two air strips have already been constructed in the vicinity of the LG-2 dam site, where site clearance has already taken place. A winter road was constructed in 1972 connecting Matagami with the LG-2 site and Fort George. A permanent road is being built along the same route, but does not coincide exactly with the winter road. This permanent road, which will be complete in 1974, will ultimately become a class "A" rural highway connected with the highway network of the rest of Quebec. Environmental studies of the project included assessment of the sites cleared in the search for fill suitable for road construction, design criteria for culverts along the road, the extent of siltation downstream from stream crossings, and bank erosion at points where the winter road crossed major rivers.

The Search for an Interlocutory Injunction Against the James Bay Development Corporation

The fundamental environmental issue presently surrounding the James Bay development is the concern of native peoples in the territory that the Development Corporation is now preventing them, and will continue to prevent them, from exercising the rights that they claim to enjoy the use of the land for hunting, fishing, and trapping as means of livelihood. The Corporation, they claim, interferes with the exercise of their rights not only through trespass, but by causing damage to the land and destruction to certain natural resources which can only in part be assessed in monetary terms. There are certainly other environmental questions involved in the development program, but the question of native rights has without doubt been the source of most of the environmental research and impact assessment.

In May 1972, lawyers acting for the Indians of Quebec Association, on behalf of the Indians of the Fort George district, gave notice of their main action — a request for permanent injunctive relief against the Development Corporation on grounds of the unconstitutionality of Bill 50 (the act establishing the Development Corporation) with respect to unsettled Indian rights in the Territory. This case has not yet been presented. Later in 1972 the lawyers decided to seek, in addition to the main action, an order of interlocutory injunction against the JBDC which would require the Corporation to cease all works interfering with those rights of the Indians remaining to be settled in the main action. The interlocutory injunction, therefore, is a form of temporary relief against the Corporation until such time as Indian rights in the Territory are finally settled by law. A hearing before the Superior Court of Quebec was granted in December 1972, and the case was heard between then and June 1973. At the time of writing, no decision on the interlocutory injunction had been announced.

A considerable amount of simplification has been necessary to provide a reasonably concise review of those elements of the interlocutory injunction hearings which are relevant to the topic of defining and evaluating environmental impact assessment. Basically, we consider first the nature of the preliminary environmental impact evidence at the time the court hearings began. This is followed by a description of the Petition seeking the interlocutory injunction and a discussion of the reasons for choosing this type of remedy. Finally, we consider the form of proof required to satisfy the court that Petitioners have the right to injunction, particularly the arguments involving "serious and irreparable damage" and the "balance of inconvenience" to Petitioners and Respondents.

The Impact Report Prepared by the Federal–Provincial Task Force — Premier Bourassa's announcement in 1971 of the development of James Bay generated concern that no environmental

evaluation of the project had been made public at a time when impact assessment was becoming an accepted part of the planning process for major construction projects. Dr. Goldbloom, the Minister responsible to the Provincial Government for the protection of the environment, undertook to find out what environmental impact studies had been carried out by Hydro-Quebec in the James Bay Territory. The conclusion must have been that insufficient research had been done, because a special joint Federal–Provincial Task Force was established in the summer of 1971 to study the environmental impact of the James Bay development program.

The Task Force, an informal group of some 20 representatives of the Provincial Government and the Federal Department of the Environment, began work in September 1971 and submitted their final report to Dr. Goldbloom in December of the same year, several months before the decision in May 1972 to start the program with the development of the La Grande basin.

The terms of reference of the Task Force, as stated in their final report, were as follows:

a) To make a broad evaluation of the impact of the James Bay hydroelectric development project on the environment of the region, taking into account that the depth of the study will be governed by the time limitations involved.

b) To identify the various elements in the ecosystem that will be affected, adversely or beneficially, by the project; to delineate their interrelationships; and to indicate their relative sensitivities and their relative importance.

c) To formulate recommendations as to any preference, from an environmental impact point of view, between the La Grande and the Nottaway–Broadback–Rupert alternative schemes.

d) To recommend the nature and scope of a more intensive long-range study which would be conducted in subsequent years; to outline a methodology that could be followed; and to suggest appropriate Federal–Provincial organizational arrangements.

The final report consisted of a 60-page document for public release supplemented by a few copies of a thick file of correspondence and memoranda which provided the basic material for the report.

The Task Force concluded that the one major impact "of potentially alarming proportions and significance" was the impact on the native populations of the area. They were careful to point out that they viewed the Indians living in the area as being economically and politically dependent on white men's society, and that the most serious impacts for the Indians would be the loss of certain "ancestral traditions" (using, as an example, navigation on the Nottaway and Broadback rivers), and the possibility of "disintegration of the existing social structure and the alienation of communities or individuals." The Task Force identified a number of other environmental impacts which they considered to be more or less unavoidable, but which at the same time they felt could be minimized by intelligent planning. These impacts included the loss of anadromous fish, the flooding of merchantable timber, the reduction in sediment discharge and saltwater encroachment at Fort George; and reflected the need for wildlife management for small mammals and fisheries resources. While reluctant to commit themselves either to the La Grande or to the Nottaway–Broadback–Rupert (NBR) developments, they concluded that "there are fewer apparent disadvantages to the La Grande alternative than to the NBR," mainly because of smaller wildlife resources — and hence lower human population density — in the La Grande catchment. It is interesting to note that in making this argument the Task Force appears to assume that their only reason for not making a quantitative assessment of the two schemes is the present shortage of adequate data, rather than any more fundamental difficulties in comparing the economic and social values of different types of resources (Joint Federal–Provincial Task Force 1971, p. 51). The Task Force concluded its assessment by comparing James Bay with the Aswan Dam, noting that the James Bay "territory is not so vulnerable to irremediable damage" as the Nile valley, and that, "In many respects, a changed ecosystem may be just as satisfactory as the original natural system, and even produce 'side benefits' to man. It is concluded that this will hold true for James Bay" (Joint Federal–Provincial Task Force 1971, p. 55). The JBDC subsequently took full advantage of the wording here.

The Task Force recommended that the entire region become a large field laboratory for interdisciplinary studies relating to environmental impact — the acculturation of the Indians, changes in mammalian ecology, changes in river morphology downstream from major impoundments, and the assessment of water quality and landscape aesthetics. They stressed the need for good baseline data which, they observe, is missing from the region, and the need for close liaison between universities and government organizations in the conduct of field research. To some extent, the

JBDC is fulfilling these recommendations by fielding parties to study fisheries, hydrography, and wildlife management under a contract, using financial support agreed to between the Federal Department of the Environment and the Development Corporation.

The philosophy behind the Task Force merits some attention. The Task Force stated explicitly that its mandate did not include answering the question: "From an environmental impact point of view, should this project proceed?" (Joint Federal–Provincial Task Force 1971, p. 1). Equally explicitly, they stated that the report does not reflect "any personal or collective reservations held by the Task Force members as to whether society really needs the project, whether there are more economical and less environmentally disturbing ways of harnessing energy resources to meet Quebec's future power requirements, or whether society should strive to restrain its electrical demands rather than increase its supply. It was assumed that these fundamental questions had been adequately considered by the authorities prior to making their decision to proceed" (Joint Federal–Provincial Task Force 1971, p. 2). In the final paragraph of the report, the Task Force reemphasized the short period they had to work in, and strongly suggested that preliminary environmental studies should have proceeded concurrently with engineering planning.

Environmental impact research in summer, 1972 — The impact report of the Federal–Provincial Task Force, the subsequent publicity releases of the Development Corporation, and first-hand experience of the early stages of construction prompted the Indians of Quebec Association to establish their own Task Force and initiate studies of environmental impact themselves. This Task Force was to collect baseline data on the wildlife and fisheries resources of the region, document the nature of the subsistence economies practiced by the Indians, and identify immediate damages to the Indians resulting from the initial stages of the project. This information was seen to be a necessary preliminary to legal proceedings for an injunction against the Corporation.

Dr. Spence of the Biology Department of McGill University (who had already, in conjunction with an anthropologist who had recently completed his doctorate on the economy of the Cree Indians, initiated studies of the wildlife resources utilized by Indians in the region) was appointed as coordinator for the Indians' Task Force. Funds were obtained from the Federal Department of Indian Affairs and Northern Development, and in the summer of 1972 teams of anthropologists and biologists went into the field to survey the subsistence economies of the Indians and to study the fisheries and mammalian ecology of the region, particularly in the small streams and wetland habitats presently used as sources of wild food by the Cree Indians. The biologists also visited a number of abandoned exploration camps which had been used by Hydro-Quebec in their preliminary investigations of the region. In addition, a group of hydrologists prepared a report, using published materials, on the effects of changes of flow regime on channel characteristics of the region; while a plant ecologist, also using previously unpublished data, prepared a report on the vegetation to be inundated by the impoundments and the consequences for wild game resources in the region.

The James Bay Development Corporation carried out some impact research at the same time, although in a much less systematic manner. Most of their attention was directed towards studying the channel of the La Grande between Fort George and the LG-2 dam site, and towards presenting the conclusions of the Task Force report, in the Cree language, to Indians in the region. This latter step appears to have caused more confusion than it resolved, partly because of linguistic difficulties and partly because the nature of the development project and its effect on the Indian way of life were left largely unexplained.

Nature of the petition seeking an interlocutory injunction — The environmental research conducted for the Indians of Quebec Association in 1972, the engineering reports for the development program, and the publications issued by the Development Corporation provided the basis for a Petition seeking an interlocutory order of injunction. The injunction would order the Respondents (the James Bay Development Corporation, the James Bay Energy Corporation, and various subcontractors) "to cease interfering in any way with Petitioner's rights, from trespassing in the territory contemplated by Bill 50 (the James Bay Region Development Act), from causing damages to the resources of the territory, and from exercising . . . the powers of municipal councils in the territory . . . until final judgment in the present proceedings for a final injunction."

The Petitioners (a group of chiefs and community leaders representing Indian communities with the territory, and Inuit communities in adjacent regions affected by the development) "allege

in their interlocutory injunction that they have and have exercised personal and usufructuary rights and hunting and fishing rights in Northern Quebec including the territory, and that the works done to date by the Respondents have adversely affected and will continue to adversely affect their rights. It is also alleged by Petitioners that irreparable damages have already been caused and will be further caused.

It is also alleged that the said Bill 50 is unconstitutional and that any rights of the Legislature of Quebec in Northern Quebec are subject to the present exclusive rights of the Indians and Inuit."

The wording above, which is taken from the final pleading of the case, contains references to several important legal concepts which have a direct bearing on the establishment of environmental rights and on the role of environmental scientists in preparing and presenting expert testimony on questions of environmental impact. These concepts are discussed below.

The usufructuary, hunting, and fishing rights can be seen, in nonlegal terms, as a special case of a more general right to continued enjoyment of the natural resources of a region and to provision of some measure of environmental protection for those resources. To identify and protect these rights it is necessary to show not only what the natural resources of a region are and why they are important, but also to show how those resources will be affected by a change in the environment such as that introduced by a hydroelectric project.

Similarly, but more directly, the allegations of adverse affects on the Petitioners' rights and of the causation of "irreparable damages" require evidence of existing or impending environmental impact for their effectiveness in court. It is evident that the value of an environmental scientist in these curcumstances depends on the skill with which he can present a realistic and socially responsible assessment of existing or threatened damages to the natural resources of a region.

Rights claimed by the petitioners — The Territory of the James Bay Development Corporation falls within the boundaries of Quebec created by the Boundary Acts of 1898 and 1912. Previously, the area had been part of Rupert's Land, the land controlled by the Hudson's Bay Company since the time of the charter establishing the Company in 1670. Rupert's Land was under the sovereignty and legislative jurisdiction of the British Crown; and the Hudson's Bay Company, although it had some legislative power of its own, was in effect an agent of the British Crown.

The Petitioners claim that the Hudson's Bay charter bound the Company to recognize Indian interest in the land as was then recognized in English common law, and that this principle was further confirmed by the Royal Proclamation of 1763 which established the government of Quebec. What this meant, in effect, was that agents of the British Crown were expected to live on peaceful terms with neighboring Indian populations, and that land could not be appropriated from the Indians without some procedure of establishing a more or less equitable treaty with them. The Petitioners also argue that both the Hudson's Bay Company charter and the Royal Proclamation were confirmatory of previously existing aboriginal rights, and did not create them. Thus, they say, Indians in the territory would have aboriginal rights independently of executive or statutory rights — rights which they also claim to have.

The Order-in-Council of the British Privy Council in 1870, which transferred Rupert's Land to Canada, required that claims from Indians regarding compensation for their lands should be settled in accordance with the practice of the British Crown in dealing with aboriginal rights. Between 1871 and 1877, seven treaties were created for parts of Rupert's Land, each of which provided an explicit surrender of rights, titles, and privileges in the lands in question. No such treaties were made for the lands on the eastern side of James Bay which now lie within the territory of the Development Corporation, despite strong directives from the Canadian Parliament that the Provinces should pay careful attention to land settlements before extending their boundaries. Consequently, lands transferred to Quebec by the Boundary Act of 1898 were not free of their Indian title to aboriginal rights. The 1912 Boundary Act imposed statutory obligation on the Quebec government to recognize Indian interests in the land, as the Canadian and British governments had done previously. However, as late as 1920 the Provincial government communicated to the Canadian Parliament that it did not then intend to take surrenders of land from the Indians of northern Quebec, so that the lands there were, in effect, still encumbered with their Indian title. In this way it was argued by the Petitioners that Indians in the territory had not so far alienated their title to the land there.

If it is in fact the case that Indian title to the land in the territory would have to be extin-

guished before the JBDC could carry out its development program, the question arises as to whether the Federal or Provincial governments have the right to extinguish the title, or whether they would have to act together. The Petitioners claim, in effect, that Indian title can be extinguished only by federal treaty and accompanying legislation, on the grounds that the Crown in right of Canada, and not the Crown in right of Quebec, is the guardian of Indian interest in the land (sect. 91, British North America Act). The constitutional ramifications of the issue of aboriginal rights belonging to Indians are certainly far-reaching.

What, then, are the rights that the Indians claim to exercise in the territory? One definition[2] used in the case is that the Indian title "though not perhaps susceptible of any accurate definition in exact legal terms, was one which nevertheless sufficed to protect the Indians in the absolute use and enjoyment of their lands, whilst at the same time they were incapacitated from making any valid alienation otherwise than to the Crown itself, in whom the ultimate title was, in accordance with the English law of real property, considered as vested."

In order to explain this title and its associated rights, the attorneys for the Petitioners made use of the doctrines of usufruct and possession as they are used in civil law, but noted that these principles are not necessarily coextensive with the Indian rights. Usufruct is "the right of enjoying things of which another has the ownership, as the proprietor, but subject to the obligation of preserving the substance thereof," and is to be distinguished from possession which, in turn, is "the detention or enjoyment of a thing or of a right which a person holds or exercises himself, or which is held or exercised in his name by another" (Articles 413, 2192, Quebec Civil Code).

There are two important differences here between usufruct and possession. First, whereas the usufructuary is not the owner of that which he enjoys, the possessor may or may not (although not necessarily) be the owner. Secondly, usufruct is a de jure right stemming from possession (i.e. the usufructuary does possess that which he enjoys) whereas possessorship is a matter of fact and not of right (de facto rather than de jure). In this case the Petitioners claimed that in their occupation of the land and enjoyments of the fruits from this land they de facto possessed the land and its resources, but furthermore, de jure they had usufructuary rights in that their interest in the land was protected by the Crown and could only be alienated to the Crown. The Petitioners were not claiming ownership of the land, but simply seeking recognition of their legal interest in the land and its resources.

There are other rights claimed by the Petitioners which relate to matters under federal jurisdiction and to specific clauses in Bill 50. First, they claim, fisheries fall under exclusive federal jurisdiction, so that only federal legislation can control the Indian right to fish (and this would also apply to hunting and trapping, in so far as they fall under the scope of section 91 of the B.N.A.).

Secondly, the Petitioners pointed out that navigable waters fall under federal and not provincial jurisdiction. The La Grande (and the Nottaway and Broadback rivers), they said, was navigable in the sense that the river is used as a canoe route by the Indians to the interior plateau for a distance of 300 miles (and this fact was not altered by the need for portages over certain sections). Consequently, it was argued, the JBDC would have to seek federal authority before developing the La Grande River, and this it had not done.

The Petitioners also claim rights which derive from clauses 5 and 43 of Bill 50: "The Corporation must see to the protection of the natural environment and prevent pollution in the Territory." And, "This act shall in no way affect rights presumed by the Petitioners to mean aboriginal rights of Indian communities living in the Territory." In this respect, the Petitioners pointed to the lack of environmental planning for the project as a whole, the possibility of water pollution, and the destruction of trap-lines by impoundments or road construction.

The above discussion shows that the enjoyment of rights and the exercise of possession in the context of the James Bay hearings involves the continued exploitation of the natural resources of a region which remains substantially unchanged by environmental damage. It is the demonstration of environmental damage and the evaluation of present and future exploitation of natural resources which requires the services of environmental scientists and which makes environmental impact assessment relevant to the court hearings. In practice, Indians and Inuit from the region testified in court on the continued exercise of their rights. This testimony was supported by the evidence of anthropologists familiar with the native peoples, and thus set the stage for the introduction of the environmental evidence and scientific testimony which is discussed below.

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[2]Strong, J., 13 S.C.R. 577, p. 608, quoted from notes prepared by attorneys for the Petitioners.

Conditions for obtaining an interlocutory injunction (especially demonstration of "serious or irreparable" injury) — Injunction is the power of the court to prevent a defendant from continuing an action which is causing harm to the petitioner, and consequently it is an important source of remedial action in environmental litigation. Injunction has its origins in equity and in the equity courts. Equity courts mainly handled suits involving the awarding of monetary damages, and the body of legal doctrine they used was intended to enlarge or supplement other systems of law which might be too rigid for the case at hand. An important feature of the injunction is the amount of discretion that can be used by the judge in deciding upon the injunction: he may require the defendant to take remedial action or to cease his activities, and he may grant either a permanent or temporary (interlocutory) injunction. If necessary, the judge may spell out in great detail the action to be taken by the defendant (for example, in the case of installing pollution abatement equipment), and if he chooses to do so he needs expert scientific testimony to make a scientifically valid order.

The basis for an interlocutory injunction, as contained in the Quebec Code of Civil Procedure, is that "In addition to an injunction, which he may demand by action, with or without other conclusions, a party may, at the commencement of or during a suit, obtain an interlocutory injunction.

"An interlocutory injunction may be granted when the applicant appears to be entitled to it and it is considered to be necessary in order to avoid serious or irreparable injury to him or a factual or legal situation of such a nature as to render the final judgement ineffectual."

The applicant for an interlocutory injunction, therefore, must "appear" to have a right to the injunction, and must show that he will suffer "serious or irreparable" injury of a factual or legal character unless an interlocutory injunction is granted. In legal usage, "irreparable damages" are damages which cannot readily be quantified and expressed in monetary terms, and include the waste or destruction of natural resources. In some respects, the concept of "irreparable damages" is akin to the resource economist's use of "intangible costs." In general, irreparable damages carry greater weight in court than damages which can readily be assigned a monetary value. Furthermore, to obtain an interlocutory injunction, an applicant has only to demonstrate prima facie that he is suffering or will suffer irreparable or serious damage, i.e. "at first appearance." Although this leaves a good deal of room for interpretation, it is taken to mean, in this case, that environmental impact evidence used in court need not be very rigorous.

Injunction can be used to protect legal rights to property by preserving it in its original condition until legal title is established, and injunction may also be granted in the event of threatened violation of proprietary rights. Proprietary rights include both usufructuary rights and the exercise of possession, and, in accordance with the views expressed above, the Indians claim proprietary rights in the land they occupy. The Petitioners can also have recourse to an injunction on the grounds of trespass by the JBDC, in the sense that trespass involves disturbing the Indians in the occupancy of their land. However, in the following, we concentrate primarily on the relation between environmental impact evidence and the demonstration of "serious or irreparable" damages or injury, since it is this problem which is of most immediate relevance to environmental scientists.

Balance of inconvenience — Finally, before discussing the environmental impact evidence, a few words must be said about the procedure used when the rights of the applicants in a petition for injunction are in doubt, which involves balancing the inconvenience to Petitioners and Respondents which would result from a decision to grant or not to grant an injunction. Petitioners did not think their rights were in doubt, but nevertheless presented a balance of inconvenience argument.

Relying primarily on the weight attached to irreparable damages, the Petitioners did not attempt to analyze their inconvenience in terms of dollars; instead they expounded on the close dependence on the land of the Indians and the almost religious significance the land and its natural resources had for them, using in particular the importance of burial grounds which would be inundated and the dislike of Indians for wasteful destruction of wildlife.

The Corporation, meanwhile, spoke at length of the losses of revenue that would follow an injunction, and the losses involved in the capital investment that had already been made in the project (probably no more than 1% of the total investment in the La Grande Complex). They also raised the question of the loss of power to Quebec society at large, although arguments involving losses to third parties in a dispute are not, in principle, admissible in a balance of inconvenience argument. (This means, in effect, that environmental costs associated with an alternative power scheme — e.g. nuclear energy — were not admissible as evidence.)

Petitioners then presented counter-proof in which they sought to show that energy growth curves provided by econometricians for Hydro-Quebec were misleading and inaccurate (in that they included items such as the increasing share of Hydro-Quebec within the Provincial power network and block sales outside the Province) to the extent that the power generated by the La Grande Complex would not be needed until the mid-eighties. The Petitioners also criticized the cost–benefit analysis conducted with respect to the choice between nuclear and hydro energy, arguing that nuclear energy would be no more expensive than hydroelectric power.

It is interesting that the balance of convenience argument used in this case does not deal explicitly with environmental costs, although some environmental scientists would feel that environmental impact assessment should include, in its terms of reference, the "negative" environmental impact — impact that would result from substituting an alternative development program or, perhaps, from no development at all.

Environmental Impact Evidence of "Serious or Irreparable" Injury

We have seen that the Petitioners, in order to obtain an interlocutory injunction, must provide prima facie proof of their rights, the exercise of their rights, and of the likelihod they will suffer "serious or irreparable" damage if an interlocutory injunction is not granted. Environmental impact evidence to demonstrate these damages was introduced by the Petitioners under the following headings, each of which will be considered in turn: hydrology; vegetation; fur bearing animals, caribou, moose, and wildfowl; and fisheries.

Hydrology — Testimony presented in the area of hydrology was mainly concerned with expanding the interpretation of hydro-meteorological data used by engineers in planning the development of the La Grande, and with evaluating the hydrological data in terms of changes in the sediment transport regime of rivers affected by the development.

The conclusions were, to some extent, self evident in that they followed directly from the engineering plans. Flow in the lower La Grande would be reduced to a few thousand cfs during the construction of LG-2, at which time the salt-water boundary would move upstream and probably require the Fort George community to change its source of fresh water. Then, as the development proceeded, the flow of the La Grande would gradually increase to a mean annual flow of 70% above the present flow. Although the effects of extremely high flows would no longer be felt, the eventual regulated flows would be sufficiently high to cause some bank erosion, and Fort George Island appeared to be especially prone to bank erosion. It was further argued that channel erosion in the lower La Grande would increase in response to the deposition of suspended sediment within the impoundments, and that bed load transport would also increase. These points were countered by witnesses for the JBDC who demonstrated that background levels of suspended sediment transport were very low (using data collected in the summer of 1972), and who also recalculated bed load transport using water slope values corresponding to reaches between sections of rapids rather than including the rapids. Naturally, the recalculated bed load transport values turned out to be considerably lower, but the Petitioners' witnesses did not have access to the necessary long profile required for the more detailed calculation. The effects of the 70% increase in the mean annual flow of the lower La Grande were left in some doubt because of the difficulty in predicting changes in channel morphology in response to sustained high flows which are nevertheless smaller than the present mean annual flood.

Reductions in the flow of the lower reaches of the Great Whale, Caniapiscau, and Opinaca rivers were confirmed, as were the flow increases in rivers such as the Kanaaupscow and Sakami which will carry flows from the diversions. Witnesses for the Respondents pointed out that erosion in rivers experiencing increased flows would be minimized because of the importance in this region of bedrock controls in determining river morphology and gradient, and hence the amount of sediment erosion and siltation. Reference was made to erosion in spillways by the Petitioners, but no specific evaluations were made. Changes in the regional water balance that would accompany the increase in water surface area in the La Grande Complex catchment were not examined.

Testimony on water quality referred to changes in the position of the salt/freshwater boundary accompanying changing flows in the La Grande at Fort George, the effects of vegetation decomposition in impoundments on the balance of dissolved oxygen and nutrients, and the possibility that fish congregating downstream from turbines might experience the effects of gas disease due to

nitrogen supersaturation. Although this testimony may have appeared quite precise, there were no existing damages for which data were available, and very limited possibilities of predicting changes in water quality with confidence. As a result, subsequent testimony introduced by the Respondents was used to demonstrate that adverse effects on water quality had not been found in the impoundments for the Churchill Falls project, and thus to minimize the importance of dissolved oxygen depletion in the impoundments containing standing vegetation.

Finally, somewhat nebulous testimony on behalf of the Petitioners that changes in river ice conditions and in the timing of ice breakup offshore from the estuaries of the La Grande, Great Whale, and Caniapiscau rivers would result in adverse effects on the movement of anadromous fish was probably quite effectively countered by a witness for the Respondents. This witness, using records of ice breakup, demonstrated that the timing of sea ice breakup in the estuaries was in any case highly variable from year to year, and that changes of the order of a few days resulting from the hydroelectric development would be superimposed on a much larger year-to-year fluctuation in sea ice conditions. In the case of the Caniapiscau estuary, which is used by salmon on their migration up the Larch River, it was argued that river and sea ice breakup would continue to be dominated by the large natural tidal range there.

In summary, evidence submitted for the Petitioners in the field of hydrology succeeded reasonably well in demonstrating adverse effects and possible damages to the Fort George neighborhood, but the order of precision in predicting the impacts was not high, and some of the testimony relating to flows elsewhere in the project area and to sea ice probably did not contribute significantly to the case for the Petitioners.

Vegetation — Environmental impact evidence relating to changes in vegetation can be considered under three headings: general statements about large-scale boreal vegetation communities; the disappearance of riparian and lake shore vegetation under impoundments and the reestablishment of new communities; and small-scale effects resulting from local disturbances.

Witnesses for the petitioners maintained that the boreal lichen woodland and its associated vegetation communities, which account for the greater part of the vegetation of the territory, is a particularly sensitive ecosystem because of the relatively few species of plants and animals present. The implication of this statement was that the region was especially vulnerable to the technology associated with the development of hydroelectric power (perhaps in the same sense that the route of the trans-Alaska pipeline was considered vulnerable, although this example was not used). Although there was probably some truth in this conclusion, it was perhaps inappropriate as environmental impact testimony because it was inadequately founded on ecological evidence and theory. It is true that for some communities, and with some theoretical justification, relationships can be drawn between species diversity in the community and the long-term numerical stability of components of the community; but it is not by any means necessarily true that the subarctic environment as a whole is necessarily a region of particularly low species diversity, nor is it necessarily true that animal populations in the region are inherently more unstable than elsewhere. Although the plant ecologist may well wish to emphasize that vegetation regeneration rates in northern Quebec are slow and that the vegetation there should not be regarded by the developer as especially resilient, conclusions such as these should be specifically stated and supported, rather than left to emerge on their own, as it were, from a vaguely worded discourse on environmental stability. Testimony such as this gave the Respondents the opportunity to argue, on even weaker grounds, that they could use ecological studies carried out over the next few years to modify, if necessary, the final stages of construction to minimize environmental impacts on vegetation. In summary, arguments concerning the sensitivity of the ecosystem appear to have contributed little to the demonstration of serious or irreparable injury to the Petitioners.

The argument that the impoundments would result in the flooding of vegetation communities along river banks and lake shores which are presently used by the Indians as hunting and trapping grounds was much more convincing. In this case witnesses were discussing a definite type of vegetation community (a shrub land of birch, willow, and alder with a rich herbaceous layer, serving as a habitat for a variety of small game) occupying a definite area and serving a definite function in the livelihood of the Indians. It was strongly argued that the loss of this habitat near Fort George, as the impoundments are filled and the flow in the La Grande rises, would mean that the Indians would have to look elsewhere for equivalent hunting grounds. Furthermore, it was

claimed that vegetation communities such as these would be reestablished very slowly, not only around the impoundments (because of the wide operating range of water levels) but also along river banks (because they would no longer receive the periodic depositions of silt which maintain the high productivity of this environment). In conclusion, testimony concerning effects of the project on wetland appears to have satisfactorily demonstrated a measure of injury to the Petitioners, although Respondents later argued that the wetland habitats included other types of vegetation community (i.e. muskeg) which is of much less importance for small game.

The argument was also raised that the development program would result in increased frequency of forest fires which would, in particular, eliminate the lichen ground cover in the open woodlands which takes several decades to regenerate. Ground and arboreal lichen are important as browse for migratory caribou in the region of the development. This argument was amply confirmed in the summer of 1973, when several serious fires in the neighborhood of the LG-2 construction site temporarily brought a halt to the activity there. Forest fires of natural origin occur in this region, perhaps to the extent that in some areas the "natural" vegetation community may be in part determined by periodic burns. Nevertheless, the point to be made was that human activity in the region tends to result in abnormally high incidence of forest fires, despite the efforts of forest fire fighting crews.

Finally, there are relatively small-scale effects resulting from local disturbances. For example, construction of roads through poorly drained country frequently causes local changes in drainage and the death of trees in flooded ground — a common sight along some Canadian highways. This problem would be accentuated by permafrost, which occurs in patches in the north of the territory. Another example would be foreshores of impoundments which experience a large fluctuation in water level, and from which the original vegetation has not been cleared. It would appear, however, that this is more of a problem in landscape aesthetics than in plant ecology, and as such makes little effective contribution to arguments concerning serious or irreparable injury to the usufructuary rights of the Petitioners.

In retrospect, testimony on the vegetation of wetlands proved to be valuable in the assessment of environmental damages, whereas broader speculations on vegetation as a whole and on the composition of the vegetation to be flooded gave Respondents the opportunity to comment on the lack of precision used by witnesses for the Petitioners in explaining environmental impacts, and so reduced the effectiveness of those portions of testimony which appeared to have demonstrated injury to Petitioners.

Fur bearing animals, caribou, moose, and wildfowl — The most important testimony on fur bearing animals was that on beaver. A specialist in beaver ecology determined from field evidence that wetlands in the vicinity of Fort George used by Indians as a source of wild food were near their carrying capacity with respect to beaver. Flooding of this habitat, by impoundments or by high flows in the La Grande, would reduce the amount of habitat available for beaver and the displaced animals would be forced to migrate. However, beaver are strongly territorial animals, and the displaced animals would experience great difficulty migrating through territory already densely occupied by other beaver. In addition, beaver rarely build lodges where the range of water level exceeds eight feet, and consequently would have difficulty in reestablishing themselves along the shores of newly created impoundments.

It was strongly argued, therefore, that the development project would result in a substantial reduction in beaver populations. Furthermore, a major reduction in beaver populations would have serious consequences for the Indians who, together with the anthropologists working with them, had testified that since the Indians had begun to live in fixed settlements for part of the year, they had come to rely on beaver as a source of wild food, rather than the caribou which they had traditionally followed. Similar but much less complete testimony was presented on muskrat, rabbit, hare, otter, and other small game.

The testimony on beaver was a particularly valuable instance of environmental impact assessment, because a scientist with a thorough knowledge of an individual species was able to determine quite precisely the autecology of the species and the likely effects of changes in habitat, and was also able to relate his work to that of the Indian witnesses and anthropologists on the use of beaver by native peoples. Ecologists are rarely in a position to be so precise in stating an environmental impact, but it is essential that the highest level of precision be reached in environmental testimony wherever possible.

Respondents replied with witnesses who testified that beaver were still present in other impoundments in Quebec. However, no proof was offered

that the beaver actually build lodges along the shores of these impoundments, and no statements were made concerning beaver densities.

Witnesses for the Petitioners claimed that woodland caribou continued to be very important in the economy of the Cree — particularly the Indians who still lived partly nomadic lives in the interior plateau lands of the James Bay Territory, where, traditionally, the Cree followed the caribou herds from year to year.

Caribou migrate seasonally in search of browse, and a major migration route for them is the region extending from Lake Bienville to the Delorme–Caniapiscau plateau (the region where the main reservoirs will be created). The survival of the caribou, especially the calves, depends on their ability to locate arboreal lichen or ground lichen under the deep snow cover of late spring. Unusually deep snow or a reduction in arboreal browse results in changes in the migration of caribou, and probably partly accounts for considerable changes in caribou populations and movements in recent historical time. At the moment, caribou seem to be increasing again (though perhaps they are only now recovering from the introduction of the repeating rifle).

Witnesses pointed to the dangers of a population decrease due to the combined effects of reduction in browse, forced changes in migration, increased predation from white hunters, and the possible instability in the vicinity of impoundments of the river and lake ice platforms used for migration.

The evidence concerning caribou was not contested by the Respondents, who did, however, argue that the caribou migration routes only just bordered on the region of the La Grande Complex development and would probably be unaffected by it.

In comparison with caribou, moose are a relatively minor source of meat for the Indians, but they do frequent the wetlands along river and lake systems, especially in the southern part of the territory. Consequently, their habitat will be reduced in the neighborhood of the hydroelectric developments and presumably some migration of moose would ensue.

Several impacts on wildfowl distributions were identified by witnesses for the Petitioners. First, there exist beds of eel grass along the coast of James Bay near Fort George which are used as food by migratory geese. The distribution of the eel grass appears to be related to the salinity gradient offshore from the La Grande estuary, although this relation is not clearly defined. However, the point was made that the distribution of the salinity gradient would be changed by the increasing flow of the La Grande, and this would probably affect the distribution of the eel grass.

Secondly, portions of the wetlands referred to previously serve as feeding grounds for geese and breeding grounds for duck — particularly black duck. Again, this source of wild food would be lost to the Indians, to the extent that existing wetlands near Fort George would be flooded and that reestablishment of similar plant communities will only take place over a long period of time (long in relation to the Indian's hunting career).

Finally, there exist nesting grounds for geese in the area of the Delorme–Caniapiscau plateau, and the area of nesting ground will be reduced in proportion to the reduction in shoreline length in the regions of the major reservoirs.

Before leaving the topic of testimony relating to the ecology of wild game, some mention should be made of the extent of the Indians' dependence on wild food. Witnesses for the Respondents maintained that in addition to a high degree of material dependence on imported goods (like ski-doos and freezers, which are now part of the equipment of the hunter) there is also an increasing dependence on store-bought food, to the extent that wild food was no longer necessary to them.

Witnesses for the Petitioners (both the Indians themselves and anthropologists) argued very strongly that this was not the case. In particular, anthropologists working in the area had noted that 80 or 90% of the food eaten was wild food, the remainder being made up of staples like tea and flour. Even at Fort George, where contact with whites is greatest, more than 50% of the food eaten is wild food, and most able-bodied men spent part of the summer hunting and trapping food for the coming winter. It was also argued that the cash incomes of the Indians at Fort George, which comes in part from local employment but mainly from Indian Affairs and Northern Development allowances, were insufficient to replace the protein contributed by the wild food with store-bought protein. Another point was that in recent years an increasing number of Indians were returning to the bush to hunt and trap wild food, and the number of trap-lines in use was growing. In this context, Petitioners argued that the system of trap-lines was itself a form of environmental conservation, in that hunters would move from one trap-line to another, without a clear concept of personal territory, to maintain a uniform balance between the amount of game taken and the amount of game available.

Fisheries — Witnesses for the Petitioners presented a considerable amount of testimony demonstrating that development of the La Grande River would involve serious reduction of the fisheries resources used by native peoples at Fort George. Three main areas of concern emerged from the testimony: loss of anadromous fish (chiefly lake whitefish, *Coregonus clupeaformis*); elimination of spawning sites caused by flooding and road construction; and the type of fishery that could be established in the impoundments.

The lower La Grande River, below the set of rapids at the site of the LG-1 power plant, supports a population of anadromous whitefish whose biology and migratory behavior are imperfectly understood, but which provide most of the fish protein for the Indians at Fort George. The whitefish move up river in midsummer and apparently spawn in the river or its local tributaries. The Indians carry out most of their fishing at this time, using traditional techniques of seining at fishing sites appropriate for present summer flows in the La Grande. Development of the La Grande River would have a serious effect on the fishery for two reasons. There would be a period of several years when the flow of the La Grande would be greatly reduced, and then the flow would increase to a mean annual level 70% above the present value. The initial period of low flow would probably nearly eliminate the spawning run for 1 or 2 yr, and the final regulated flow for the La Grande Complex would bring fundamental changes in the distribution of whitefish below the LG-1 rapids and therefore in the type of fishery that could be continued by the Indians. Also, the dam site at LG-1 will be constructed on the rapids and will probably occupy the fishing sites currently used by native peoples. In addition, during the period of low flow there would be a substantial risk of water pollution from sources such as concrete pouring and fuel oil spillage. Furthermore, even if LG-1 were somehow omitted from the development program, the flow regime of the La Grande would be so high that the rapids at LG-1 might no longer serve as suitable spawning grounds.

Secondly, it was claimed that the inland populations of brook trout (*Salvelinus fontinalis*), lake sturgeon (*Acipenser fulvescens*), and walleye (*Stizostedion vitreum vitreum*) would be adversely affected near impoundments because of the drowning-out of rapids where these fish presently congregate and spawn. Brook trout might be replaced, in part, by lake trout, but it was difficult to foresee whether spawning sites would be available for fish in lakes which have been created by inundating woodland. Access roads to construction sites cross many small rivers which now support populations of brook trout. Siltation in rivers downstream from crossings would interfere with feeding behavior and might interfere with spawning grounds. No consideration had been given to fish passage in the choice of culvert design by highway engineers, and a witness for the Petitioners pointed out that culverts could well have been chosen to facilitate fish passage. Finally, aerial photographs taken above the permanent road in the sections where it runs over alluvial silts and clays demonstrated that the effects of siltation in the streams could be seen from the air to extend for distances of at least 1½ miles away from the road. Witnesses for the Respondents argued, rather weakly, that changes in flow regime in the rivers of the La Grande Complex would result in the formation of additional rapids, and that brook trout would simply change their feeding and spawning grounds.

The Respondents also argued that the impoundments would have a high fish productivity, which could be used to advantage by the Indians. To illustrate they refered to piscicultural practices in Russian dams and to the fact that fish could still be taken from other impoundments in Quebec. In reply, it was pointed out that although the nutrient status of the impoundments would no doubt increase with the decomposition of terrestrial vegetation, an increase in heterotrophic activity or primary productivity would not necessarily result in high fish productivity if there was at the same time not only a shortage of spawning sites but also periodic dissolved oxygen stress imposed on the fish populations. Witnesses for both Petitioners and Respondents testified that the most prolific species of fish in the impoundments was likely to be northern pike (*Esox lucius*). Pike are readily used as food by the Indians, but they tend to prey heavily on the whitefish which the Indians themselves use intensively. A witness for the Petitioners also pointed out that northern pike are intermediate hosts for the cestode *Triaenophorus crassus* and the tapeworm *Diphyllobothrium latum*, which can be conveyed to human hosts from flesh which is improperly cooked. Witnesses for the Petitioners also argued that witnesses for the Respondents could not necesarily generalize from experience gained in other Quebec reservoirs to the case of the La Grande Complex.

Testimony was introduced to argue that a reduction in the run of salmon up the Koksoak (the lowest part of the Caniapiscau) en route to

the Larch River would follow the reduction of flow down the Caniapiscau. Gas disease resulting from nitrogen supersaturation in water discharged from turbines was also introduced as a possible problem for fish congregating in the lower La Grande River.

In summary, the strongest part of the fisheries testimony dealt with whitefish in the lower La Grande River. Other portions of the testimony, though valuable, were weakened by the lack of precise information on the type of fish populations that would be established in the impoundments and the difficulty in determining the extent to which road construction would actually cause loss of spawning grounds for brook trout and other species of fish.

Review — Before leaving the subject of the environmental impact testimony used in the court hearings, I would like to make some general remarks about the overall organization and presentation of testimony by the witnesses for the Petitioners.

The Petitioners started out at the beginning of the hearings with very little specific information on the environment they were dealing with, but by the end of the hearings they had amassed a large quantity of evidence which was somewhat uneven in quality. Some of this evidence was put together very well and used to good effect — especially the testimony on wild game and fisheries and the supporting testimony relating to hunting and trapping practices of the Cree Indians. However, in other areas the evidence was less internally consistent and less cogently argued. This is partly, of course, because the necessary information was unavailable, but probably also because the scientists who prepared the evidence and gave testimony tried to draw too many conclusions using too little information. Inevitably, this had the effect of confusing the central issues of the case, and gave rise to the criticism of the lawyers for the Respondents that the scientific witnesses for the Petitioner tended either to be inconsistent in their evaluation of different impacts, or to fail completely to state the importance of a possible impact. In other words, different types of impact were being discussed in a way which made it very difficult for the nonecologist to establish for himself a scale of priorities or of probabilities in weighing up the environmental impact evidence.

The second point is related to the first and concerns comunication between the environmental scientist and the lawyer. In my opinion, the lawyers for the Petitioners showed imagination and perceptiveness in following patterns of ecological reasoning. The scientific witnesses who were called were being asked to give their "expert opinion" on environmental issues, and it was made clear to them that this meant giving opinion and not statements of fact. In practice, however, this led to some confusion, because it was never quite clear what an opinion was and how it was to be reached. The scientists, in general, were unused to making specific recommendations on environmental policy and consequently unused to the basic problems of presenting impact assessments, and the legal requirement that they need only provide prima facie evidence of environmental damages did not necessarily help. Consequently, when reading through transcripts of expert testimony and the final pleading in the case, one is left with the feeling that what is presented to the judge is often not an explicit, simple statement of impact assessment, but a discontinuous catalogue of possible effects without the necessary reasoning or ordering of priorities. Perhaps the conclusion to be made here is that the environmental scientists, for their part, should place less emphasis on cautious experimental design and more emphasis on reaching practical and useful decision. Also, the lawyers themselves should make it a little more clear what kind of statements are needed from their witnesses; and perhaps they should also explain a little more of the legal background to the experts presenting testimony.

The final remark concerns the expense and time involved in collecting and presenting environmental evidence, especially the time and expense incurred by the Petitioners. The securing of background information in the summer of 1972 was expensive (several hundred thousand dollars) and there is no doubt that the presentation of the case before the Superior Court over a period of 6 mo was also very expensive. It appears that most of the Petitioners' expenses are being met by the Department of Indian Affairs and Northern Development, but this does not alter the fact that the procedure is expensive.

The preparation of scientific testimony is expensive, as is the task of inducing Indians from the Territory to testify in court. The problem in the case of scientific testimony is that in order to obtain coverage of as many topics of environmental concern as possible, the lawyers for the Petitioners had to look across the country for suitable witnesses, who often came from great distances. The preparation of an expert witness before he gives testimony may take as much as a

day for every hour he appears in the witness box, and it is a trying and exhausting procedure for the lawyers and the scientists. (In all, 179 witnesses testified, and occupied the court for over 20 wks.)

My point in emphasizing this is that, as a general procedure for solving conflicting interests arising from environment impacts, the full legal procedure of seeking an interlocutory and then a full injunction is impractical. There must be a simpler method of resolving the issues raised in this case, even if the experience gained as a result of the James Bay hearings does serve to illustrate the role of environmental scientists in making impact assessments. In most cases it is simply not possible for a minority group, whose rights to the enjoyment of their environment are being threatened by a major development, to raise the necessary funds for a lengthy injunction hearing.

At the time of writing this, the decision of the judge was not known, and so there was no way of answering the question "How useful, after all, was the environmental impact evidence?" However the Appendix, written after the paper was finished, does attempt to answer this question.

Environmental Impact Assessment in the Light of the James Bay Experience

The review which concluded the preceding section provided an analysis of some of the problems that were involved in introducing environmental impact evidence in court. The point was made there that the hearings for the interlocutory injunction turned out to be very time-consuming and costly, and that alternative means must be found to facilitate the process of environmental impact assessment, regardless of the fact that in this case the central issue was to determine the nature of aboriginal title to natural resources in a region. In this section, we consider some of the broader questions of the role of environmental impact assessment and analysis which stem from this conclusion and which I feel have been raised but not answered in the paper so far. We shall be concerned with two basic questions. 1) What kind of environmental impact statements and assessments were really needed for the James Bay Development Program? 2) How should the environmental studies have been organized and the analysis of impact presented?

Environmental studies could have been carried out in the area of the James Bay territory during the time that hydro-meteorological data were being collected to determine the hydroelectric potential of the rivers of northern Quebec. These studies would presumably have included basic floristic and faunistic surveys combined with some consideration of the ecology of individual members of the fauna; some attention might also have been paid to the productivity of the different vegetation communities and to the fisheries resources in rivers and lakes of the region. Some basic limnological surveys might also have been included in the hydro-meteorological program. Such studies would have yielded a much more complete picture of the vegetation of the territory and the wildlife it supports than was at any time available to the scientists working during the injunction hearings.

But would a program such as this have provided a comprehensive and effective environmental impact assessment of the development of the La Grande Complex, or of the other drainage basins? In any absolute sense, the answer is probably no, for two reasons. First, no matter how detailed the environmental studies were, they would not have prevented the hearings for the interlocutory injunction from taking place. The court hearings concerned legal title to land and not environmental impact assessment in its own right; the environmental evidence was used to determine whether rights to the enjoyment of natural resources were being violated, not whether (on environmental impact grounds) the development should proceed. Secondly, it is extremely difficult to conceive of an impact statement for a development of this size which would be sufficiently precise to satisfy both the general public and the academic ecologists working in universities (the impact assessment of the Alaska pipeline illustrates this point). There are several reasons for this. First, large quantities of data do not themselves simplify the task of environmental impact assessment. Secondly, the predictive power of established ecological theory is simply not powerful enough to evaluate certain long-range, but possibly significant, impacts; the interpretation and evaluation of these long-range impacts would be a source of continuing and unresolved debate. Finally, there is ample room for disagreement as to the proper content of environmental impact assessments as long as there are no widely accepted criteria for the preparation of impact reports.

The second question concerns the organization of environmental impact studies and impact analysis. If we accept that much more detailed inventories of biological resources should have been prepared (and this certainly would have been desirable), we then have to decide who

should conduct these studies and who should interpret the assessment of environmental impact.

The probable answer is that the developers themselves should take the initiative and responsibility for studies of environmental impact. First, it is unlikely that an independent party could have taken on the task, unless perhaps a government body (Federal or Provincial, or a combination of both) was specially constituted for such a purpose. To some extent, the responsibility of continued environmental impact assessment in the James Bay case does fall on teams of government scientists, but the impartiality and objectivity of a government-appointed team remains questionable, particularly in the case of James Bay, where a Crown Corporation is itself the developer. On the other hand, it is quite unrealistic to expect that the Indian and Inuit peoples — or for that matter any other interested group which felt that it would be adversely affected by the development — should take on the responsibility for impact studies. Without the provision of funds for field research and court proceedings, the Petitioners in this case would have been quite unable to field the necessary scientists and obtain the necessary environmental evidence, and this would certainly be true for any other interested group. Normally, funds for this kind of investigation of a hydroelectric project would simply not be available.

The only practical alternative is to require the developer (in this case Hydro-Quebec or JBDC) to commission the necessary environmental studies and submit the results of research to independent review. It would be necessary to appoint a review board for this purpose. There are two ways of answering the criticism that studies carried out on behalf of the developer would lack objectivity and impartiality. First, one function of the review boards would be to prevent obvious breaches of trust on the part of the developer. Secondly, the developer would in any case have to entrust the environmental impact studies to persons competent to carry out the research, and one may hope that in time there will evolve a body of experienced environmental scientists who are capable of making respected impact reports and assessment. These would be people whose professional reputations would depend on their skill, conciseness, and integrity in preparing impact assessment and analysis. At the moment, we must recognize that environmental scientists recruited from the milieu of the universities have not been required to stake their reputations on their environmental counsel and have not, strictly speaking been held responsible for their assessments. In this context, the development of some mechanism for making environmental scientists accountable for their recommendations would be highly desirable.

What, then, should be the format of impact assessments and analysis? In the United States, an environmental impact matrix developed by a team from the United States Geological Survey (Circular 645, 1971) has been used as a checklist of items to be considered in impact assessment, and a matrix of this kind was actually included in the report of the Federal–Provincial Task Force on the environmental impact of the James Bay Development. Such a matrix is certainly useful as a checklist, but there is some risk that the completed matrix might be regarded as some form of assessment in its own right. This would certainly be unfortunate if it were to become generally true. For the purposes of presenting the final assessment and its analysis, it would appear more reasonable, and certainly more manageable, if the environmental impact assessment team were to set out in point form each of the major impacts expected, at the same time making it perfectly clear what they consider to be the priorities and likelihood of the different impacts. It should also be made quite explicit what impacts can be predicted with confidence, and which impacts are not directly accessible to prediction within a reasonable amount of time and with a reasonable input of research effort. Perhaps also the assessment team should concentrate its research efforts on the impacts of highest priority, so that these impacts can be stated with the highest attainable level of precision. On the other hand, a lengthy discourse on a variety of more or less intangible impacts will only serve to confuse the basic environmental issues to be resolved. For these reasons, I consider the skill and integrity of the scientist in setting out reports in a straightforward and unambiguous manner to be a paramount virtue.

If we apply this reasoning to the case of the James Bay court hearings, it could be argued that the necessary environmental impact evidence could have been presented much more simply by introducing about 10 witnesses to testify on a few selected topics of immediately demonstrable importance to the Indians: i.e. the ecology of beaver and other small mammals and caribou; the vegetation communities of the wetland habitats; fisheries; bank erosion and sediment transport in the lower La Grande River; and the extent of the flooding of wildlife habitat used by the Indians resulting from the creation of impoundments and changes in the flow regime of rivers. To satisfy

the conditions for the interlocutory injunction, the Petitioners were only required to provide prima facie evidence of serious or irreparable damage to themselves, and not necessarily a complete catalogue of all possible environmental consequences of the development. However, the foregoing remarks reflect the point of view of the environmental scientist, and it may well be that from the legal viewpoint extensive corroboration of environmental testimony was highly desirable.

In conclusion, environmental scientists were successful in presenting the necessary environmental impact evidence for the interlocutory injunction hearings, but I feel that the procedure involved some duplication of effort and the introduction of a substantial amount of evidence that was sufficiently lacking in precision to be less relevant to the hearings than the lawyers hoped.

Summary

1) The development of the hydroelectric potential of the La Grande is part of a much larger program of development of the mineral and biological resources of a region of at least 130,000 square miles presently under the administration of the James Bay Development Corporation and, indirectly, of Hydro-Quebec.

2) The program to develop 8330 MW of power from the La Grande River using a system of four main power plants and a network of reservoirs and diversions from adjacent drainage basins is described.

3) An explanation is given of the hearings for an interlocutory injunction against JBDC in the interest of Indians and Inuit in the region affected by the development program. The disputed rights of the Indians are discussed, and it is shown that demonstration of the existence of these rights and proof that these rights may be violated required evidence of both existing and future environmental impacts.

4) An analysis is presented of the environmental impact testimony that was used to demonstrate the probable damages resulting from changes in hydrology, vegetation, animal ecology, and fisheries. General comments are included on the usefulness of this testimony in demonstrating environmental impact in the context of the James Bay court hearings.

5) An attempt is made to evaluate the procedures involved in environmental impact assessment by considering in turn the problems of defining the content of an environmental impact assessment, of determining who should conduct the assessment and how the analysis should be presented, and the adequacy of the environmental impact testimony used in the hearings for the interlocutory injunction.

Acknowledgments

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Appendix

The Judgment on the Hearings for an Interlocutory Injunction Restraining the James Bay Development Corporation

Judge Malouf of the Quebec Superior Court granted an interlocutory injunction against the James Bay Development Corporation in a 170-page decision released on November 15, 1973. The Court ordered the Respondents (the JBDC and the organizations and individuals responsible to it):

a) To immediately cease, desist and refrain from carrying out works operations, and projects in the territory described in the schedule of Bill 50, including the building of roads, dams, dykes, bridges and connected works.

b) To cease, desist and refrain from interfering in any way with Petitioners' rights, from trespassing in the said territory and from causing damage to the environment and natural resources of the territory.

The court found that the Indians had personal and usufructuary rights in the territory, that they had been in possession and occupation of the lands since time immemorial, and that the Government of Canada recognized Indian interest in the land and entered into treaties with Indians when it desired to obtain lands for settlement or for other purposes. According to the 1912 Boundary Act, the Province of Quebec appeared to be under statutory obligation to proceed in the same manner as the Government of Canada, i.e. to obtain the prior agreement of Indians and Eskimos before settling or developing the lands they occupy. No evidence was found that the Indian title in the territory had been legally extinquished. Because the decision concerned an interlocutory rather than a final injunction, it was not necessary for the judge to provide an exact definition of the nature of the Indian title: it was sufficient to note that the Indians appeared to have rights in the territory.

Judge Malouf concluded, from the evidence of Indian occupation of the land and the exercise of their rights, "that they have a unique concept of the land, make use of all its fruits and produce, including

all animal life therein and that any interference therewith compromises their very existence as a people" and that "they wish to continue their way of life."

The judge continued: "In a case of this nature the sums of money expended, even if substantial, must not be permitted to cloud the issues. . . . The proof has convinced me that if these works are allowed to continue, a factual situation will soon occur which will render any final judgment ineffectual because it will then be impossible to put parties in the position they would have been in had the works not been carried out."

Because he considered that the rights of the Indians were not in doubt and that they had a clear right to an interlocutory injunction, Judge Malouf explained that he need not consider the balance of inconvenience to Petitoners and Respondents. Nevertheless, 20 pages of the judgment are devoted to an analysis of the balance of inconvenience. After dismissing on technical grounds a number of the monetary damages claimed by the Respondents, he said, "I find it difficult to compare such monetary loss to the damages such a large group of people will suffer. The rights of Petitioners to pursue their way of life in the lands subject to dispute far outweigh any consideration that can be given to monetary damages"; he therefore concluded that, "the balance of inconvenience militates in favor of Petitioners."

Judge Malouf also criticized the Respondents for continuing work during the court hearings, and for including in their balance of inconvenience argument evidence of costs incurred while the court hearings were taking place.

Nearly one-third of the decision is devoted to an examination of testimony relating to environmental impact. After outlining statements made by each of the scientific witnesses, for both Petitioners and Respondents, the judge built up a thorough picture of the interrelationships between the different types of environmental impact described by the witnesses. It is interesting that the judge was prepared to accept predictions of future damages by scientific witnesses, and did not appear to have attached special importance to the demonstration of immediate damages. During the court hearings, attorneys for the Petitioners considered proof of existing damages to be especially important to their case, even though, at the time of the hearings, such damages were still comparatively slight.

Judge Malouf concluded by expressing his strong belief that the environmental evidence clearly demonstrated irreparable damage to the Petitioners: "In reviewing the evidence I find that Petitioners are justified in their apprehension of injury to the rights which they have been exercizing. Damages to the flora and fauna have already taken place. Further considerable damage will be caused by the works which are presently going on. Still more extensive and more serious damages will occur as the work progresses.

"The major rivers in the territory will be completely transformed. The flow of some will be cut off, reduced, increased, or diverted. Others will be transformed into a series of lakes. Changes in the flow of rivers and the creation of reservoirs will flood many lakes. The beds and banks of rivers will be eroded. Areas of dry land will be flooded. The normal spring flood will not occur. The wetland habitat on which so many animals depend will be destroyed. The lichen areas will be reduced significantly . . . the evidence discloses that the works will have an adverse affect on the birds, the fish, the animals and aquatic life generally. The number of animals will be reduced significantly. Petitioners will no longer be able to make use of the fruits of the soil. They will no longer be able to hunt, trap and fish in the areas affected. The ecological balance which existed in the region will be seriously disturbed. The mutual relations between the organisms and their environment will be completely upset. The environment will be changed. . . .

"In view of the dependence of the indigenous population on the animals, fish, and vegetation in the territory, the works will have devastating and far reaching effects on the Cree Indians and the Inuits living in the territory and the lands adjacent thereto."

The treatment of environmental testimony in the judgment on this case serves to illustrate some of the problems of evaluating statements of environmental impact raised earlier in the paper. Judge Malouf provides a clear description of the types of environmental impact associated with the development of hydro-power, and he describes in detail how the different impacts are related. One consequence of this treatment is that the testimonies of each of the scientific witnesses appear as a set of statements, each of equivalent value; apparently, it is not the purpose of the judgment here to provide a explicit discussion of discrepancies in environmental testimony, or an evaluation of those impacts which might carry greater weight in the legal decision on the case. As a result, although there is a full physical and biological description of the development Territory, there is little of the reasoned argument connecting evidence of impact with the conclusions as to whether the impact merits remedial action — an argument which would play an important part in decisions on impact assessment in other contexts.

It is hardly surprising that this should be true. Judge Malouf was being asked to make a decision based on a considerable mass of unfamiliar environmental evidence, and he was in no position to question the scientific basis of the testimony. In any event, to meet the requirements for the interlocutory injunction, the Court required prima facie evidence of environmental damage — not rigorous proof. Nevertheless, in my opinion, the treatment of the environmental evidence in this case is to some extent a reflection of the way in which testimony was given. The scientists themselves were not required to summarize in their testimony their opinion as to the relative severity or priority of the impacts under discussion, nor did they have to state the adequacy of the information at their disposal for predicting future impacts (although many witnesses made it very clear

that they were testifying in regions which were largely unexplored from both a geographical and scientific point of view). Even so, Judge Malouf's task might not have been any easier even if these requirements had been followed; the problem of deciding whose opinion to accept would still remain.

Judge Malouf's decision was taken to the Quebec Court of Appeal by the JBDC 1 wk later. Within 2 days, the Court decided to suspend the interlocutory injunction until the appeal had been heard. This decision was granted unanimously on the grounds that Bill 50 was in the interests of Quebec society and was constitutional until rendered otherwise by the final action of the Petitioners for a full injunction. In making this move, the Court of Appeal did not consider the text of Judge Malouf's judgment, and did not refer to the issue of aboriginal rights. The Indians appealed the ruling of the Court of Appeal before the Supreme Court of Canada. The latter Court, on December 21, in a three-to-two split decision, decided that it would be improper for the Supreme Court to reconsider the suspension of the injunction while the appeal of the Development Corporation was still before the Provincial Court of Appeal.

Meanwhile, construction in the La Grande River basin is proceeding on schedule, and it now appears that a fait accompli, as forecast by Judge Malouf, will have been created by early summer of 1974, at least as far as the site of LG-2 is concerned. It remains to be seen whether the problem of aboriginal title to the land in this region will be settled through negotiations between the Provincial Government and the Indian and Inuit peoples, or whether the issue will finally be resolved through the courts and federal legislation.

Most of this paper is based on court transcripts, personal communications, and unpublished documents deposited in court as exhibits. For that reason, no attempt has been made to provide detailed references. Further information on the subject matter can be found in the five references below:

BEALS, C. S. [ed.] 1968. Science, history and Hudson Bay. 2 vol. Dep. Energy, Mines, Resources, Ottawa, Ont. 000 p.

BOURASSA, R. 1973. James Bay. Harvest House, Montreal, Que. 000 p.

HARE, F. K. 1959. A photo-reconnaissance of Labrador–Ungava. Mem. 6, Geogr. Br., Mines Tech. Surv. Ottawa, Ont. 83 p.

LOWE-MCCONELL, R. H. [ed.] 1964. Man-made lakes. Academic Press, Inc., New York, N.Y.

RICHARDSON, B. 1972. James Bay, the plot to drown the North Woods. Sierra Club, Clarke Irwin & Co., Toronto, Ont. 000 p.

More detailed information may be found in:

Joint Federal–Provincial Task Force. 1971. Preliminary study of the environmental impacts of the James Bay Development Project, Quebec.

ROUSSEAU, SAUVÉ, WARREN AND ASSOCIATES. 1972. Report on the hydro-electric development of the La Grande River. 3 vol. Quebec Hydro-Electric Commission, Montreal, Que.

The following reports were prepared for the James Bay Task Force of the Indians of Quebec Association and the Northern Quebec Inuit Association:

COOK, B., G. CLOUGH, J. MICHAUD, R. COUTTS, AND J. A. SPENCE. 1972. Reports on vegetation and related fauna of the Fort George and Upper Caniapiscau Rivers.

SALISBURY, R., et al. 1972. Not by bread alone – the subsistence economies of the people of Fort George, Paint Hills, Eastmain, Great Whale, Fort Chimo, and the Nitchequon Band from Mistassini.

SPENCE, J. A. AND B. MEDFORD, 1972. The fish of the Fort George River and Upper Caniapiscau River drainages in the relation to the proposed hydroelectric development.

TAYLOR, C. H., et al. 1972. Effects of the James Bay Development Scheme on flow and channel characteristics of rivers in the area.

Ecological Changes Due to Hydroelectric Development on the Saint John River[1]

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RUGGLES, C. P., AND W. D. WATT. 1975. Ecological changes due to hydroelectric development on the Saint John River. J. Fish. Res. Board Can. 32: 161–170.

Most of the available head of the Saint John River is utilized for hydroelectric development by a series of dams located from the headwaters almost to tidewater. Seven of these hydroelectric dams are described in terms of location, power generation, size of impoundment, operating schedule, and fish passage facilities. Access to upstream spawning areas by Atlantic salmon (*Salmo salar*) and other anadromous species has been impeded, while ecological changes in the impoundments have favored such species as the alewife (*Alosa pseudoharengus*) and the white sucker (*Catostomus commersoni*). Hydroelectric developments on the main stem of the river have reduced the capacity of the river to assimilate organic wastes and have resulted in a reduction of dissolved oxygen content. Fish kills have occurred due to low dissolved oxygen in the headponds and to supersaturation of nitrogen below the lowermost dam. The combination of impoundments and high pollution load results in the heterotrophic food chain dominating the biological carbon flow.

RUGGLES, C. P., AND W. D. WATT. 1975. Ecological changes due to hydroelectric development on the Saint John River. J. Fish. Res. Board Can. 32: 161–170.

La plus grande partie de la charge de la rivière Saint-Jean est utilisée pour des fins hydro-électriques, grâce à une série de barrages répartis depuis la tête des eaux presque jusqu'à la zone des marées. Nous décrivons sept de ces barrages hydro-électriques en termes d'emplacement, génération de pouvoir, étendue des eaux de retenue, schédule d'opération et installations pour le passage des poissons. L'accès aux frayères d'amont du saumon atlantique (*Salmo salar*) et autres espèces anadromes a été entravé, alors que les changements écologiques des eaux de retenue ont favorisé des espèces telles que le gaspareau (*Alosa pseudoharengus*) et le meunier noir (*Catostomus commersoni*). Les développements hydro-électriques de la branche principale de la rivière ont diminué la capacité de la rivière à assimiler les déchets organiques, ce qui a eu pour effet de réduire la teneur en oxygène dissous. Des mortalités de poissons se sont produites par suite d'une carence d'oxygène dissous dans les réservoirs d'amont et d'une supersaturation d'azote en aval du barrage le plus bas. Les réservoirs de retenue, combinés à une lourde charge de polluants, font que la chaîne alimentaire hétérotrophe l'emporte sur l'écoulement du carbone biologique.

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No use of water, with the possible exception of gross waste disposal, can have as massive an effect on the original ecology of an area as large-scale hydroelectric development. Many of these effects are well documented from hydroelectric development in several regions of the world. The purpose of this paper is to describe the changes that have taken place in the general ecology of the Saint John River due to hydroelectric development, with special reference to the interrelationship of hydroelectric development, water pollution, and fisheries.

The Saint John River (Fig. 1) is one of the larger North American rivers draining into the Atlantic Ocean. It drains a portion of northern Maine in the United States and adjacent areas of the provinces of Quebec and New Brunswick in Canada. The river is 676 km (420 miles) long, with a total fall of about 481 m (1,578 ft) between its source in the state of Maine and tidewater at Fredericton, N.B. It drains an area of 54,930 km^2 (21,210 square miles). A distinctive feature is an extensive estuary forming the last 96 km (60 miles) of the river.

In the early history of Canada the river provided a transportation route to the interior of the country. Settlement began in about 1604, when

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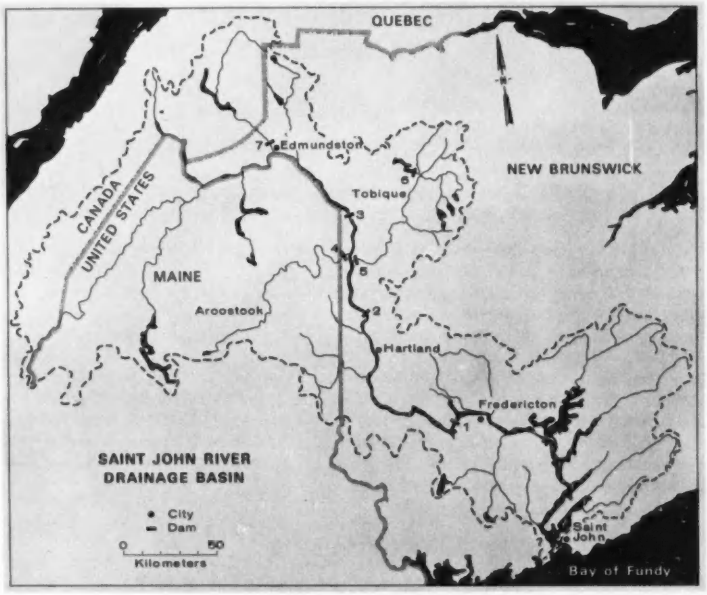

FIG. 1. Saint John River Basin. The dams indicated by number are 1) Mactaquac, 2) Beechwood, 3) Grand Falls, 4) Tinker Dam on the tributary Aroostock River, 5) Tobique Narrows Dam on the Tobique River, 6) Sisson Dam on the Tobique system, and 7) the Edmundston Dam on the Madawaska River.

European immigrants began to farm the fertile valley. The population today totals about 420,000 people, including 300,000 in New Brunswick, an estimated 100,000 in the state of Maine, and 20,000 in Quebec. The extensive forest cover (85% of the land area in the basin) forms the natural resource base for the leading industry, which is pulp and paper production. The second major industry in the basin is food processing, particularly that based on the potato harvest.

The hydrology of the Saint John River basin was described extensively in the 1969 Montreal Engineering report to the Atlantic Development Board. The mean annual discharge at a location midway between Mactaquac and Hartland (Fig. 1) is 691 m^3/s (24,400 cfs) from a drainage area of 38,721 km^2 (14,950 square miles). From this same drainage area, the minimum monthly average flow recorded for the period 1932–52 is 77 m^3/s (2,710 cfs). The lowest flows normally occur during winter, with other low flow period during late summer and early fall. Maximum flows normally occur during the spring runoff, although rainfall floods can occur during any season.

Because of its importance to the province of New Brunswick, the river has been the subject of extensive and comprehensive studies. The latest, initiated in 1970 under the aegis of the Saint John River Basin Board, is designed to provide a water management plan for the Canadian portion of the basin. The objective of this project is to provide for the improvement of water quality without jeopardizing the area's economic base. An encouraging aspect of this study is the emphasis given to understanding the ecology of the system.

Hydroelectric Development on the River

The Maritime Provinces are not endowed as favorably with hydroelectric potential as other parts of Canada, and so it is not surprising that the potential of the Saint John River was extensively developed for power generation. The available head of the river is utilized in a cascade fashion by several dams located from headwaters almost to tidewater. Due to the limited storage possibilities on the system, a relatively low degree of flow regulation has been achieved. The main

TABLE 1. A summary of hydroelectric plant data from dams located on the Saint John River and tributaries (from Montreal Engineering Co. Ltd. 1969).

Development	Location	Year Installed		Rated head ft.	No. of units	Turbines		Generators	
		First unit	Latest unit			Unit capacity (*hp*)	Total capacity (*hp*)	Unit capacity (*kw*)	Total capacity (*kw*)
Mactaquac	main stem	1968	1972	110	4	140,000	560,000	100,000	400,000
Beechwood	main stem	1957	1962	57	2	45,000		36,000	
					1	55,000	145,000	40,500	112,500
Grand Falls	main stem	1928	1931	125	4	20,000	80,000	15,750	63,000
Tinker	Aroostook R.	1922	1965	85	2	2,000		1,500	
					2	5,000		3,520	
					1	33,000	47,000	20,800	30,840
Tobique	Tobique R.	1953	1953	70	2	13,500	27,000	10,000	20,000
Sisson	Tobique R.	1965		135	1	12,500	12,500	10,000	10,000
Edmundston	Madawaska R.	1918	1918	21	2	1,030	2,060	750	1,500
Total							873,560		637,840

stem plants at Grand Falls, Beechwood, and to a lesser extent Mactaquac, approach "run of the river" type, and hence power generation is largely governed by the natural flow of the river. Although seasonal changes in stream flow are impossible due to lack of storage, short-term changes in flow result because of the way in which the plants operate. These stations are basically peak-load plants, generating power in response to demand, and hence rapid alterations in flow downstream result. Table 1 summarizes design features of seven hydro plants on the Saint John River.

The Mactaquac hydroelectric development is located 18 km (11 miles) upstream of Fredericton and is operated as a peak-load plant during low flow periods and as a base-load plant during high flow periods. Fish passage facilities are provided, and a large Atlantic salmon (*Salmo salar*) hatchery forms part of the fishery conservation provisions for this development. Although only four generators are installed, provision has been made for the ultimate installation of six units. The earth and rock-fill dam creates a reservoir 97 km (60 miles) long with a maximum usable storage of 455 million m^3 (370,000 acre-feet). The mean annual natural flow in this region of the Saint John River is approximately 765 m^3/s (27,000 cfs). The normal drawdown of the reservoir is from 1.5 to 2.1 m (5 to 7 ft), with the maximum anticipated drawdown of 6.1 m (20 ft). Maximum potential power output is in the order of 600,000 kw after all six generators have been installed.

The Beechwood hydro development is located 130 km (80 miles) upstream of Mactaquac and its operating schedule is similar. Fish passage facilities are provided in the form of a mechanical hoist or elevator. The earth-fill and concrete dam creates a reservoir 35 km (22 miles) long, with a maximum usable storage of 42 million m^3 (34,000 acre-feet). The mean annual natural flow in this region of the river amounts to about 680 m^3/s (24,000 cfs). The normal drawdown is between 0.9 and 1.2 m (3 and 4 ft) with a maximum of 4.6 m (15 ft). The maximum power output is about 113,000 kw.

The uppermost main stem hydro development on the Saint John River is located at a natural impassable waterfall called Grand Falls, about 64 km (40 miles) upstream of Beechwood. This was the first hydroelectric dam constructed in the Canadian portion of the basin. Since anadromous fish were never able to pass Grand Falls, no fish passage facilities were installed in the dam. The dam forms a reservoir 41 km (25 miles) long with a maximum storage of 26 million m^3 (21,000 acre-feet). The mean annual natural flow from a

drainage area of 21,885 km² (8,450 square miles) is 399 m³/s (14,100 cfs). Normal drawdown is 0.3–0.6 m (1–2 ft) and maximum operating drawdown is 2.1 m (7 ft). The maximum power output is 63,000 kw.

Hydroelectric development on the Saint John River basin began in 1906 with the damming of the Aroostook River in Maine. No fish passage facilities were provided at Tinker Dam until 1936. When the dam was rebuilt in 1965, no provision was made to pass fish due to the heavy load of organic pollution entering the Aroostook River from food processing and starch plants and from domestic sources. Water storage for power generation is augmented by two headwater impoundments, which provide about 98 million m³ (80,000 acre-feet). The maximum power output is 31,000 kw and the mean annual natural flow is approximately 113 m³/s (4,000 cfs).

A major salmon-producing tributary, the Tobique River, was dammed near its mouth in 1953. A pool and weir fishway was incorporated in this structure. The total power development scheme includes four storage dams constructed in the headwaters. One of these headwater dams (Sisson) includes 10,000 kw from one generator. The Tobique Narrows Dam provides a maximum output of 20,000 kw from an average annual natural flow from 4,325 km² (1,670 square miles) of 81 m³/s (2,860 cfs). The Tobique Dam creates a reservoir 16 km (9.5 miles) long with a maximum storage of 12 million m³ (9,800 acre-feet). Total storage available from all five dams is about 258 million m³ (210,000 acre-feet). A drawdown of 18.6 m (61 ft) occurs in the Sisson Lake reservoir, whereas the normal drawdown for the Tobique impoundment is 0.6 m (2 ft).

A small hydroelectric development exists on the Madawaska River near the town of Edmundston, New Brunswick, about 56 km (35 miles) above Grand Falls. Since anadromous fish do not inhabit any tributaries above Grand Falls, no fish passage facilities are provided. An average annual flow of 19.3 m³/s (683 cfs) occurs at this point, originating from a drainage area of 2,797 km² (1,080 square miles). Maximum power output is 1,500 kw. No operating storage is provided by the dam; however, a storage dam located in the headwaters provides 124 million m³ (101,000 acre-feet).

Effects of Hydroelectric Development on Anadromous Fish Populations

The obvious adverse effect of hydroelectric development on the migration patterns of anadromous (spawning in fresh water and growing to maturity in the sea) fish was recognized at an early stage in the development of the river for power generation. One of the reasons for this was the Federal Fisheries Act, which requires the owner of a dam to provide a fish passage facility where the Minister of Fisheries determines it to be necessary. A variety of techniques has been employed on the Saint John River to provide access to freshwater spawning areas for Atlantic salmon. The desire to protect this highly valued commercial and sport fish has initiated some rather extraordinary measures to ensure the continued existence of Saint John River Atlantic salmon.

Conventional fish ladders were utilized at the dams constructed on the salmon-spawning tributaries, such as the Aroostook and Tobique rivers. The main stem dam at Beechwood utilized an ingenious fish hoist or elevator to transport upstream migrating adult salmon over the dam. By far the most elaborate and expensive fish passage facilities are located at the Mactaquac Dam. These include a collection gallery, cantilevered from the powerhouse wall and supplied with a constant flow of water so as to provide an attraction to returning adult salmon. Entrance to the gallery is by way of six submerged gates spaced along its length. The gates, or weirs, adjust automatically with the elevation of the tailrace, which can fluctuate as much as 5.5 m (18 ft). The salmon, and other upstream migrating species, move against the current in the gallery to a holding pool, where a mechanical crowder forces them into a sorting facility. The sorting facility, comprised of two interconnected pools, is designed to exploit the jumping behavior of Atlantic salmon to isolate them from the large numbers of other migrating species. All species are placed in large transportation trucks for movement upstream past the dam.

Although upstream passage of fish at run-of-the-river dams can be more or less solved by properly designed physical or mechanical aids located at the dam sites, the safe passage of seaward migrating juveniles through impoundments and over dams has created more serious problems. In particular, the multiple exposure of smolts (juvenile salmon seaward migrants) to turbine injury and mortality was believed to be too high for those salmon populations reproducing in areas upstream of Mactaquac to perpetuate themselves successfully. It was decided, therefore, to construct a salmon hatchery 2 km below the Mactaquac Dam to supplement the smolt

production adversely affected by habitat destruction and turbine mortality.

Despite extensive hydroelectric development and impaired water quality in much of the main stem reaches of the river (see following sections), Atlantic salmon still return in relatively large numbers to the Saint John River. Total commercial and sports catches were derived from statistics gathered by the Fisheries and Marine Service. An estimate of the spawning escapement was deduced from angling statistics and counts of salmon obtained from dams, fish weirs, and sampling traps throughout the system. The annual average commercial and sport fishery catches for 5-yr periods and the corresponding estimates of spawning escapements are presented below:

Time period	Commer. fishery	Sport fishery	Spawning escapement	Total
1949–53	19,400	3,600	8,000	31,000
1954–58	11,800	2,300	6,700	20,800
1959–63	13,000	2,100	4,600	19,700
1964–68	19,000	1,700	5,300	26,000
1969–73	3,200	1,700	8,800	13,700

The recent decline in salmon abundance is believed due to several causes. Elson and Kerswill (1964) present evidence that suggests that persistent forest spraying with DDT over two salmon generations seriously reduced salmon production in the most productive salmon-producing tributary, the Tobique River. It is interesting to note, however, that the Tobique Salmon Club successfully claimed damages from the New Brunswick Power Commission for losses attributed to the construction of the Tobique and Beechwood dams. The Tobique River sport catch declined from 2206 fish in 1951 to 65 fish in 1957. The low catch in 1957 coincided with Elson and Kerswill's prediction, on the basis of DDT spraying, that the adult stocks for the Tobique would be 55% of the normal. It seems, therefore, that the construction of the Beechwood Dam in 1957 worsened an already serious situation with respect to returning adult salmon. After cessation of DDT spraying in the Tobique watershed, the salmon population rose again to relatively high levels of abundance, but the sports catch did not recover (Dominy 1973). The Tobique River lost its reputation as a salmon angling stream during the mid-1950s, forcing many guides and outfitters out of business. Thus, even when a good run of fish appeared, angling effort was too low for an effective harvest.

There is evidence (Gardner 1971) from Scotland to suggest that declines in the number of salmon in a river after dam construction may be followed by a progressive increase in their numbers. It may be that, if the dam represents only a physical barrier to upstream migrating adults, salmon populations will stabilize close to the levels of abundance that were present prior to dam construction, provided well-designed fish passage facilities are incorporated into the dam structure. When dam construction floods out spawning areas or has other deleterious effects, the abundance of salmon stocks will decline unless successful remedial measures are taken. In the case of the Tobique Dam, very little spawning area was destroyed and evidence suggests that this dam has not had a serious adverse effect on the salmon runs entering this spawning tributary.

Following construction of Beechwood Dam in 1957, salmon angling below the dam improved and salmon abundance in regions above Beechwood was generally high (Dominy 1973). It was not until the construction of the Mactaquac Dam in 1967–68 that environmental changes in the river seriously exceeded the salmon's capacity to adapt.

One environmental change directly attributable to the Mactaquac power development was the increase in dissolved nitrogen gas directly below the powerhouse in the summer of 1968 (MacDonald and Hyatt 1973). This was not due to air entrainment during spillage over the crest of the dam such as described by Harvey and Cooper (1962) or by Beiningen and Ebel (1970). The source of the nitrogen was believed to be from air vented into the turbines to reduce negative pressures during weekend periods of sustained low generating levels. Death by gas-bubble disease was positively identified in both Atlantic salmon and American eels.

American shad (*Alosa sapidissima*) populations have declined dramatically following construction of the Tobique, Beechwood, and Mactaquac dams. Early field observation records indicate that a shad population existed in the Tobique River prior to dam construction. Their presence at the Tobique Dam fishway was noted for a few years after the dam was built, but there was a rapid decline in abundance following completion of the dam. At the Beechwood fish collection facility shad numbers declined from a high of 1,487 in 1960, 4 yr after construction of the dam, to zero in 1967. At the Mactaquac Dam, shad runs declined from 38,838 in 1968 to 7,363 in 1973.

The reason for these declines is not known for certain, but one factor involved is the partial

failure of the upstream fish passage facilities to provide satisfactory access to upstream areas. Observations at the Tobique fishway indicated that shad did not readily ascend the fishway. Stevenson (1899) observed that "shad cannot or will not run up through fishways that are readily used by alewives." The environmental changes due to dam construction that are detrimental to shad reproduction are not well understood. Walburg and Nichols (1967) present an extensive review of the life history of the fish and the factors responsible for its decline in the United States, but do not provide any data on the indirect effect of dams as opposed to the direct exclusion from spawning areas. Since shad are pelagic spawners and the headponds thermally stratify, the eggs could settle into the hypolimnion where either temperature or oxygen conditions would be unsuitable for development. For whatever reasons, it seems clear that hydroelectric development on the Saint John River has had a devastating effect on the shad population.

Whereas shad and salmon populations have declined in abundance since the construction of hydroelectric dams on the Saint John River, two other anadromous species, the alewife (*Alosa pseudoharengus*) and the closely related blueback herring (*Alosa aestivalis*), have increased in abundance. Annual combined counts of both species at the Mactaquac fish collection facilities are as follows:

Year	Numbers
1968	22,000
1969	106,000
1970	85,500
1971	369,000
1972	1,205,000
1973	1,445,000

Although the exact reasons for the increase in alewife and blueback herring have not been studied, both these anadromous species require relatively still water for spawning and reach their greatest abundance in river systems containing an abundance of lake area. As mentioned earlier, they also appear to negotiate fishways more successfully than shad. The change from a lotic environment to a lentic environment upstream of dams has increased the spawning and nursery area available for these two species. Their proliferation has caused congestion problems in the fish-transport facility at the Mactaquac Dam. Consideration is now being given to methods of harvesting surplus stocks of these relatively low value species.

During the summer months the largest fish populations in the Mactaquac impoundment are the fry of the alewife and blueback herring. Although normally plankton feeders (Bigelow and Schroeder 1953), the Mactaquac populations also feed extensively (27% by weight) on macrobenthic animals (Watt and Duerden 1973).

Effects on Water Quality and Aquatic Ecology

Although considerable thought was given to devising methods to ameliorate the adverse effects of hydroelectric development on the migrations of anadromous fish in the Saint John River system, the importance of the more indirect environmental changes was underestimated. In particular, the reduction in the capacity of the river to assimilate organic wastes was not fully recognized.

One influence of the dams is the slowing down of water transport. Water which would normally flow from Edmundston to the downstream side of Mactaquac Dam in about 3 days, now can take as long as 3 mo. Slowing down the water gives more time for the biochemical oxygen demand (BOD) to consume the available oxygen and also reduces the rate at which the water is reaerated. The result is a reduction in dissolved oxygen content in the river. Figure 2 shows a profile of the dissolved oxygen content in the surface water of the Saint John River in August 1969 at various locations from above Edmundston to the mouth of the river at Saint John. The largest single source (48% of the total) of BOD loading originates 415 km (258 miles) above the river mouth at the pulp mill in Edmundston, New Brunswick, and at the paper mill directly across the river in Madawaska, Maine. Other important contributors to the total BOD load are about a dozen potato-processing and starch plants located in the middle portion of the river. A further 20% of the total BOD load is released by two pulp and paper mills situated in the city of Saint John, N.B., at the river's mouth.

The aquatic ecology of the Grand Falls impoundment is almost entirely that of effluent decomposition. Gas exchange at the air–water interface cannot supply oxygen fast enough to meet the respiratory oxygen demand. Oxygen concentrations in the water are, therefore, very low, and occasionally the entire impoundment goes anaerobic. Only those decomposers (sewage bacteria, fungi, sludgeworms) adapted to very low oxygen levels can live in Grand Falls impoundment. Fish are largely excluded, except for a few visitors who enter from unpolluted tributary

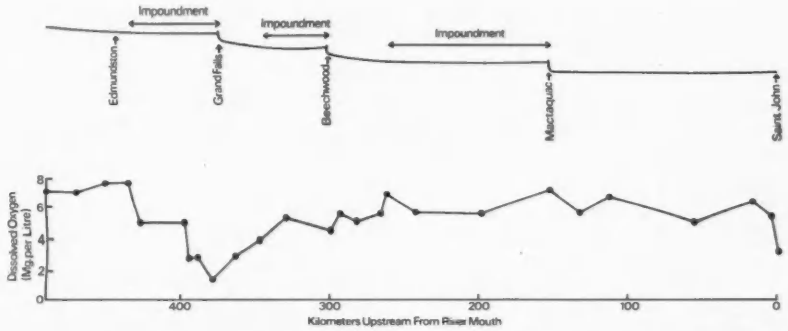

FIG. 2. Dissolved oxygen (in surface water) profile for the Saint John River during a low flow period in August 1969.

streams and may stay in the pond during periods of temporary high oxygen levels. When oxygen concentrations fall again they must retreat or suffocate. When anaerobic water blocks the escape routes, fish kills occur.

A conspicuous feature that affects the aquatic ecology within the Grand Falls impoundment is the ubiquitous wood pulp. This material is in suspension in the water and it forms a loose sediment or ooze over much of the bottom. There are no thick bottom deposits of the ooze, just a few centimeters overlying rocks and gravel. Each spring when the flood gates of the dam are opened the entire pond is scoured by the currents and the previous year's sediment deposits are flushed down the river. Animal life at the bottom of the pond is largely confined to sludgeworms of the family of Tubificidae living in the pulp ooze. Sludgeworm densities as high as 150,000 worms per square meter have been reported for the Grand Falls impoundment (Watt et al. 1973). By far the commonest form of life in the impoundment, however, is the sewage bacterium *Sphaerotilus natans*.

The pulp and paper plant effluents from Edmundston–Madawaska, reinforced by municipal effluents from riverside communities and from the food-processing and potato starch plants, have reduced the ecology of the Beechwood impoundment to a state not very different from that of Grand Falls. The commonest form of life is sewage bacteria. Their respiratory oxygen demand exceeds the rate of reaeration, resulting in low oxygen levels in the water, especially during the winter and summer periods of low flow. The animal life of the bottom consists almost exclusively of sludgeworms (up to 560,000/m^2).

The Mactaquac impoundment represents an ecological recovery zone. Here the rate of effluent loading does not exceed the ability of the aquatic communities to adapt. In the Grand Falls and Beechwood impoundments the primary producers account for less than 1% of the biological carbon budget (Watt 1973). In the Mactaquac impoundment primary production accounts for about 15% of the carbon budget (17 g C · m^{-2} · y^{-1} of primary production and an effluent carbon consumption of 140 g C · m^{-2} · y^{-1}; Watt 1973). The primary producers require sunlight and chemical nutrients for photosynthesis. The principal nutrient requirements are for carbon, nitrogen, and phosphorus. The median concentrations of total phosphorus, total nitrogen, and total organic carbon in the three main-stem impoundments and one (Tobique) on a relatively unpolluted tributary are presented in Table 2. These values are medians of 35–60 samples collected by the Environmental Management Service during the 17-mo period from June 1, 1971, to November 1, 1972.

It is apparent from Table 2 that relative to Tobique, the main-stem impoundments are nutrient-enriched, especially with regard to nitrogen and carbon, which are undoubtedly available in quantities adequate to support massive algal blooms. This may not be true of phosphorus, however. Of the three principal nutrients, phosphorus is in shortest supply and a lack of available phosphorus may occasionally be a limiting factor for plant growth and photosynthesis. The most significant environmental factor limiting the rate of primary production is underwater penetration of sunlight. On the main stem of the river the high turbidity and color effectively limit the photic zone to the top 2 or 3 m. Only that small fraction (about 15% in Mactaquac) of the phyto-

TABLE 2. Median concentrations (35–60 samples) during 1972 of total phosphorous, total nitrogen, and organic carbon and estimates of primary production from the four major impoundments on the Saint John River.

Impoundment	Total[a] phosphorus ($mg\ P \cdot m^{-3}$)	Total[b] nitrogen ($mg\ N \cdot m^{-3}$)	Organic[c] carbon ($mg\ C \cdot m^{-3}$)	Primary[d] production ($gC \cdot m^{-2} \cdot yr^{-1}$)
Tobique	20	185	5,000	22.2
Grand Falls	33	970	16,800	8.5
Beechwood	35	890	12,500	12.5
Mactaquac	37	870	12,000	16.9

[a]Acid digestion followed by colorimetric estimation on autoanalyzer.

[b]Total Kjeldahl nitrogen (acid digestion followed by ammonia titration) plus nitrate and nitrite (cadmium reduction and colorimetric nitrite estimation on autoanalyzer).

[c]Oxidation followed by infrared analysis.

[d]Estimated from chlorophyll concentration and underwater light penetration.

plankton population that is near the surface of the water can be actively photosynthesizing at any one time. There is also evidence for a short period (about 2 wk during the 1972 summer low flow period) of phosphate availability limiting the primary production rate in Mactaquac impoundment.

Estimates of annual primary productivities for 1972 (see Table 2) are relatively low. They are comparable to levels reported for oligotrophic and mesotrophic aquatic systems and certainly do not indicate a high level of eutrophication. Surface blooms of blue-green algae (*Anacystis* sp.) do occur in the quieter bays of Mactaquac headpond, but to date they have not caused any major nuisance.

Even in the Mactaquac impoundment, the predominant feature of the aquatic ecology is the overwhelming contribution of organic carbon from upstream industrial effluents. In response to this organic carbon loading, the heterotrophic food chain leading to the macrobenthos dominates the biological carbon flow. The heavy oxygen demand from this decomposer community, especially during low flow periods, reduces the water quality by oxygen depletion to the point where the less tolerant species (notably salmonid fishes) cannot survive.

The macrobenthic animals collected from the bottom of Mactaquac headpond are mostly Tubificidae (sludgeworms) and Chironomidae (bloodworms). Both of these groups are associated with polluted conditions. The highest sludgeworm density found in Mactaquac headpond was 45,000 worms per square meter, and this was near the upper end of the headpond. Toward the downstream end of the headpond sludgeworm densities are lower. The sludgeworm population densities and species compositions on the Saint John River are well correlated with chemical indicators of water pollution levels (Watt et al. 1973).

The impoundments have provided an ideal environment for the common white sucker (*Catostomus commersoni*) and the longnose sucker (*C. catostomus*). Quantitative data are not available, but gill and trapnet results indicate the presence of dense populations of these two species in Beechwood and Mactaquac impoundments (Meth 1973). It is not surprising that bottom-feeding fish would be very successful in these environments in view of the relatively immense food supply available in the macrobenthos, particularly the sludgeworms.

Mactaquac impoundment also supports large populations of smallmouth black bass (*Micropterus dolomieui*) and chain pickerel (*Esox niger*). Although both these species are at present largely ignored by local anglers, they do represent a future sport fishery potential. They also represent a source of predation to juvenile salmon, the extent of which has not yet been determined.

Discussion

The major effect of dam construction on the Saint John River has been worsening of an already serious pollution problem. The resulting aquatic ecology is not, however, in a state of eutrophication as is common in other polluted bodies of water. The organic effluent load is so

great that a state of heterotrophication prevails. The resulting aquatic ecology resembles a gigantic sewage treatment system with the impoundments serving as settling ponds providing secondary and some tertiary treatment for the effluent load. In the Saint John River impoundments the decomposer communities have expanded in response to the heavy input of organic effluent carbon. In the relatively unpolluted impoundment above Tobique Dam, the estimated production of macrobenthos in 1972 was 1.9 g C/m². In the grossly polluted main-stem impoundments of Grand Falls, Beechwood, and Mactaquac, the estimated macrobenthos productivities were 47, 175, and 22 g C/m², respectively (Watt and Duerden 1973). Approximately 90% of the macrobenthos productivity in these three impoundments is attributable to *Limnodrillus hoffmeisteri* and *Tubifex tubifex* (sludgeworm) species associated with grossly polluted conditions. It is estimated that decomposers in Grand Falls and Beechwood impoundments consume in excess of 2000 g of organic effluent carbon/m² per yr, while primary production is less than 1% of this.

The water quality problems associated with the heterotrophication of the Saint John River impoundments could be at least partially solved by a system of low flow augmentation and dilution of pollution-free water from clean tributaries. This would require the construction of storage impoundments near the headwaters so that water could be released during low flow periods. Studies with a computer simulation model (H. G. Acres Limited 1971) indicate, however, that periods of low flow do not necessarily correspond with the worst water quality conditions. The explanation is that 48% of the total effluent load is released at Edmundston, and during a low flow period can cause anaerobic conditions in Grand Falls headpond. If the flow of water is then increased by low flow augmentation, the result is a flushing of the problem further downstream. Thus, in Beechwood and Mactaquac impoundments, the worst water quality conditions tend to occur at greater than minimum flows. Low flow augmentation could improve conditions between Edmundston and Grand Falls, but conditions downstream would probably worsen.

Water quality has had a direct effect on the management of Atlantic salmon. For instance, the reduction in dissolved oxygen has affected the availability of salmon stocks for angling on the Saint John River. In the summer of 1969 water conditions in the Hartland area were considered to be unsuitable, based on oxygen content, for the release of salmon being trucked upriver from Mactaquac. This decision proved to be sound, since in August an extensive kill of suckers occurred in the Hartland area. The mortality was believed to be the result of a lack of dissolved oxygen.

A reduction in dissolved oxygen also impedes the natural migration pattern of salmon. Tagging of returning salmon in the estuary in June has indicated that early-run fish can spend up to 4 mo in the river prior to ascending a tributary stream to spawn. Low flow conditions in the smaller tributary streams during the summer months prevent salmon from moving up these streams until the fall rains occur. Poor water quality in the river in 1967 and 1968 is believed to have delayed the entry of adult salmon to the river. This delay allowed the commercial fishery operating near the river mouth to take a major portion of the available stock. This situation brought about restrictive regulations in the commercial fishery in order to protect the stock from over-exploitation.

The operation of the fish hatchery is also threatened by poor water quality. Fish kills in the hatchery have occurred due to nitrogen supersaturation and due to toxicity associated with lignosulphonates. Although the lignosulphonate concentrations in themselves were not lethal, they indicate a stage of effluent breakdown from the pulp and paper mills upriver. The toxic constituents causing fish mortality, therefore, could be associated with the effluent from these mills.

The problem of nitrogen supersaturation due to air venting of the Mactaquac turbines during periods of low generating levels has been at least partially solved by the installation of a modified air valve system. The system will be evaluated over the next year or two to determine its effect on reduction of nitrogen supersaturation as well as any detrimental effects to the turbine.

The interrelated nature of hydroelectric development, water pollution, and fishery conservation has resulted in the development of a comprehensive salmon management plan to ensure the preservation of this important commercial and recreational resource. The location and size of the Mactaquac Dam requires handling all fish destined for the upper regions of the river. A portion of the run is maintained by artificial means. Each year 200–300 salmon are selected for use as broodstock and their progeny are reared in the hatchery and released as seaward migrating smolts. The remainder of the run is transported upriver to supply angling and natural spawning. Since 1969, the commercial and sport fisheries for

salmon have been regulated so as to ensure an adequate spawning escapement. Fundamental to the success of this fishery management program, however, is effective pollution abatement.

In 1970, the Saint John River Basin Board issued an interim plan for the reduction of gross pollution in the river. The Board recommended that pollution abatement action be taken at once at all major effluent sources. The pulp mill at Edmundston has since installed an effluent treatment system achieving a 20% reduction in BOD, and the owners of the mill have entered into an agreement with the province of New Brunswick to achieve an eventual 95% reduction. Little progress has yet been made on pollution abatement at the two pulp mills in the city of Saint John, and the BOD load from these sources has in fact increased. In the food-processing industry, process improvements have reduced loading from the largest effluent source by about 30%, and the rising price of potatoes has forced all of the starch plants out of production. The end result of all these events has been a reduction of about 20% in the total BOD load entering the river.

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Impact of the Bennett Dam on the Peace–Athabasca Delta[1]

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The Peace–Athabasca Delta Project was an intergovernmental (Canada, Alberta, Saskatchewan) study group assembled to assess possible downstream effects of the W. A. C. Bennett Dam on the Peace–Athabasca delta and Lake Athabasca. Low water levels on the delta coincided with the upstream filling of the Williston Reservoir during 1968–70, exposing thousands of acres of marsh and lake bottom, advancing plant succession (toward the less desirable willow communities), threatening access of migrating fish to the delta's spawning lakes, and reducing nesting habitat for waterfowl and overwinter habitat for muskrats. The resultant drastic decline in the muskrat population affected the economy of Fort Chipewyan and the lifestyle of its native people because of their dependency on trapping.

The long-term effects of the changed regime are predicted to decrease important shoreline of perched basins by approximately 50%, to cause plant succession to proceed uninterrupted for longer periods of time, thereby accelerating the ageing of the delta, to shift plant zones to lower elevations around lake margins, and to reduce the vertical ranges and area of early successional plant communities by as much as 50%. Waterfowl production is expected to decline by 20–25%, and muskrat populations will decrease by 40–65%. Bison grazing meadows will suffer losses although moose habitat is expected to improve. The decrease in water levels will increase the risk of a delay in walleye spawning runs to the delta lakes.

A number of remedial alternatives were examined to seek a solution to restoration of water levels. A fixed-crest weir on an outlet channel of Lake Athabasca was selected to satisfactorily restore the natural regime. Another site, even though seemingly more ecologically suitable, had serious drawbacks including potential ice problems, the need for navigation lock and fishway, and much greater size and expense. A monitoring program adequate enough to determine the success or failure of the remedial structure was also recommended.

TOWNSEND, G. H. 1975. Impact of the Bennett Dam on the Peace–Athabasca delta. J. Fish. Res. Board Can. 32: 171–176.

Le projet du delta de la Paix–Athabasca a comporté la formation d'un groupe d'étude intergouvernemental (Canada, Alberta, Saskatchewan) dans le but d'évaluer les effets que le barrage W. A. C. Bennett pourrait avoir en aval sur le delta de la Paix–Athabasca et sur le lac Athabasca. Les niveaux de l'eau ont baissé dans le delta à mesure que s'est rempli le réservoir Williston en 1968–1970, ce qui a exposé des milliers d'acres de marécages et de fonds de lacs, accéléré les successions de plantes vers des communautés de saules moins désirables, réduit les aires de nidification des oiseaux aquatiques, restreint les territoires d'hiver des rats-musqués et causé un déclin considérable des populations, et enfin compromis l'accès des lacs de fraie du delta aux poissons migrateurs. La diminution subite des rats-musqués a affecté l'économie de Fort Chipewyan et le mode de vie des indigènes à cause de leur dépendance du trappage.

On prédit qu'à long terme le changement de régime réduira d'environ 50% la ligne de rivage des bassins surélevés, permettra à une succession de plantes d'évoluer sans interruption pendant de plus longues périodes, hâtant ainsi le vieillissement du delta, déplacera les zones végétales vers des niveaux plus bas sur le bord des lacs, et réduira jusqu'à 50% la distance verticale et la superficie des communautés végétales du début de la succession. On s'attend que la production d'oiseaux aquatiques diminue de 20–25% et que les populations de rats-musqués soient réduites de 40–65%. Les prairies de broutage des bisons subiront des pertes, alors qu'on s'attend à une amélioration de l'habitat de l'orignal. L'abaissement du niveau de l'eau augmentera le risque de retard dans les remontées de dorés vers les lacs du delta.

[1]Prepared for the Canadian Conference on Freshwater Fisheries Research held at Ottawa, Ont., on January 7–8, 1974.

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On a étudié un certain nombre d'alternatives pour remédier à la situation et rétablir les niveaux d'eau. On s'est arrêté à une enceinte à crête fixe sur un chenal de sortie du lac Athabasca comme moyen satisfaisant de rétablir le régime naturel. Un autre site, bien que paraissant plus propice au point de vue écologique, présentait de sérieux inconvénients, y compris danger de glace, besoin d'écluses pour la navigation et de passes migratoires pour les poissons, installation plus grande et plus coûteuse. On a de plus recommandé un programme de contrôle suivi suffisant pour déterminer le succès ou l'échec de l'installation.

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THE Peace–Athabasca Delta Project was a study group formed to investigate the downstream effects of a hydro dam already under construction. The W. A. C. Bennett Dam, located on the upper Peace River in British Columbia, was conceived in the late 1950s, was under construction by 1962 and as construction reached the final stages in December 1967, the dam was closed and the upper Peace River came under the control of man. The Peace River forms part of the Mackenzie River drainage basin. It flows southeast from the Rocky Mountains into Alberta and then northeast to join the outlet channels of Lake Athabasca to form the Slave River. It drains an area of 113,000 square miles and has an average annual flow of 80,700 cfs.

Lake Athabasca is one of the largest lakes in the vast Mackenzie River drainage system. It is 200 miles long and straddles the Alberta–Saskatchewan border in the northern part of the provinces. It receives water from the Peace River and two other major rivers, the Athabasca and the Fond du Lac. The east end of the lake is oligotrophic, with the depth extending to 400 ft, whereas the west end is less than 10 ft deep in the mud flats of the Peace–Athabasca delta.

In the summer of 1968, following closure of the Bennett Dam the previous winter, water levels in Lake Athabasca failed to rise as high as usual, and in fact peaked almost 5 ft below levels that had been established in the preceding 10 yr. Low water levels on the delta and in the lake persisted during 1969 and also in 1970, but it was not until the latter part of 1970 that sufficient public concern was voiced to generate enough interest in assessing the problem.

In January 1971 a symposium was held at the University of Alberta to discuss what information was available relating to a possible changed water regime on the delta, and if water levels had changed, what would be the effects on the ecology of the area. Over 15 papers were presented, and a considerable discussion was generated among the 150 persons attending the symposium.

One recommendation underway in January was that of structuring a task force to determine the ecological and social requirements of the delta, Lake Athabasca and the townsite of Fort Chipewyan, and to attempt to improve water levels by the spring of 1972 if required.

A second objective was to determine whether operation of the Shrum Generating Station at the Bennett Dam would have any long term effects on the water-level regime of the Peace–Athabasca delta. And if this were so, what the effects would be on the flora and fauna, and the requirements of local people, and what alternatives were available to counteract any undesirable effects.

Some 30 federal and provincial agencies, plus a large number of nongovernmental agencies and individuals participated in the project at the various stages of the investigation.

The water levels of Lake Athabasca and the delta are controlled by the amount of water flowing in from three major rivers, the Peace, the Athabasca and the Fond du Lac, and by the elevation of the Peace River in relation to Lake Athabasca. In spite of its large size, Lake Athabasca undergoes considerable annual fluctuation, as much as 10 ft in 1 yr, but usually averaging about 5.5. Lake Athabasca is usually at its lowest in late winter, when river flows are the lowest, but begins to rise during spring breakup, and historically rose to a peak in mid-July as flows in the river reached their maximums. Prior to 1968, the Peace River experienced flood flows averaging 311,000 cfs or greater for 10 days usually in June, and these high flows were sufficient to prevent water from flowing out of Lake Athabasca, and quite often created a southward flow of Peace River water into the delta. At the same time the Athabasca River runoff reaches a peak, causing water levels in the lake and in the delta to begin their summer rise.

During 1968 through 1971 the high flows in the Peace River did not reach the delta. Even though the Bennett Dam is located some 730 miles upstream from the delta, it effectively controls 50% of the flow in the Peace River at Lake Athabasca. During the 4 yr there was a net

storage in Williston Lake of 50 million acre feet of water. Standard streamflow routing procedures were used to reconstruct the estimated natural flow of the Peace River adjacent to the delta, assuming that the Bennett Dam had not been closed. The effect of the closure of the dam was to capture most of the flow, particularly the large volume of summer runoff from the upper regions of the Peace River, allowing only a very low flow to pass. Flood flows on the Peace River adjacent to the delta were reduced by as much as 200,000 cfs, and this meant that the river levels were as much as 10–12 ft lower than they would have been without regulation. The low levels on the Peace River allowed the water to flow out of Lake Athabasca much more rapidly than during the normal spring and summer. It was calculated that during the filling phase of the Williston Reservoir, the water levels of Lake Athabasca remained an average of 2.5 ft lower than under undisturbed conditions. The waters of the Peace–Athabasca delta underwent similar declines. Although 2.5 ft does not seem a large reduction in lake levels, it represented a drop below the level required to flood the delta.

What environmental changes occurred in response to the lower water levels? The 1.5 million-acre delta is composed of hundreds of lakes and marshes and stream channels, some of which are isolated and depend on flooding for refilling, and some of which are connected to the major rivers entering Lake Athabasca. The annual summer flooding which occurred during the first half of the 1960s was enough to keep most of the perched or satellite basins full until 1968. In the 3 yr following 1968, approximately 36% of the perched basin shoreline disappeared and there was a reduction of more than 38% in water surface. The larger lakes connected to Lake Athabasca and the river channels lost water more rapidly, and within a year or two about ½–¾ mile of mud flats was exposed around the shore edges. Between 1968 and 1970, this represented over 124,000 acres of mud flats. Seeds lying dormant or blown in from nearby germinated during the first summer of exposure, and by 1971 new meadow and willow communities were becoming well established in their second or third year of growth.

Muskrats felt the effects of low water levels in the perched basins. Many of the marshes which supported harvestable populations in the 1960s were either frozen to the bottom in winter or became dry. The harvest of muskrats within Wood Buffalo Park portion of the delta declined from 144,000 animals during the winter of 1965–66 to 32,000 during the winter 1969–70, 8,000 in 1970–71 and less than 2,000 during 1971–72 winter.

The short-term effect on waterfowl nesting was an improvement over pre-1968 conditions. This is because historical summer flooding wiped out waterfowl nests, whereas during 1968–71 no flooding occurred during the critical nesting season. But at the same time the perched basins which are important to breeding ducks and geese and are dependent on floods were drying up. If this situation had continued, waterfowl production would have declined below pre-1968 levels.

Waterfowl also use the delta for molting during the summer when they lose their flight feathers. Molting habitat was reduced during the 4-yr period because some of the emergent marsh vegetation became stranded. The migrant waterfowl, both during spring and fall, found attractive mud flats and shallow water areas which probably exceeded the amount present before 1968. The pre-1968 regime was also attractive to staging waterfowl, however, because of the seasonally fluctuating levels which maintained early successional plant communities.

The Peace–Athabasca delta supports about 10,000 wood buffalo within the national park. They depend on the extensive sedge and grass meadows interspersed with willow cover for food and shelter. The changes in the water regime since 1968 had little immediate effect on the bison herd within the park. In fact the lack of midsummer flooding may have improved the calf survival. But if low water levels were to continue, it is evident that plant succession would proceed to the point where willow communities would eventually dominate the sedge and grass meadows. If this occurred, it would result in a decline in the amount of grassland habitat important to the buffalo.

There are approximately 800 moose inhabiting the delta and surrounding area. It was determined that the moose habitat was affected to only a small degree by the reduced water levels, since the moose prefers the more advanced successional stages, and these have been the least influenced by water level changes during the 4-yr period.

Low water levels in the delta and lake threaten several species of fish. The northern pike (*Esox lucius*) is a common inhabitant and it is believed that with the low winter levels, freezing to the bottom or oxygen deficiency caused winterkill in many localities. Northern pike are fairly sedentary and were not observed leaving the shallow marshes to winter in the deeper river channels.

The delta supports a breeding population of

goldeye (*Hiodon alosoides*). They were observed to migrate into the delta from the deeper river channels in spring to spawn in the shallow delta lakes, and then leave the delta in the fall to migrate up the Peace River to winter. During the spring of 1971, water levels at the entrance to one of the major spawning lakes was considered just sufficient for the fish to enter. They were able to enter and spawn successfully, and there was sufficient flow out of the lake in the fall for the adults and young to return to the river.

The walleye (*Stizostedion vitreum vitreum*) is another fish species which uses the shallow delta lakes to spawn. This species is harvested in Lake Athabasca, both in Saskatchewan and in Alberta portions, but it is believed that the majority of adults spawn in one or two of the larger delta lakes. They move upriver early in the spring just before breakup, and it was observed that on one spawning lake, Richardson Lake, the outlet was frozen to the bottom at a time when the fish were prepared to enter. Their spawning was thus delayed for a week or two until spring floods opened the lake. The success of the spawning activity cannot be determined until the age structure of the population is examined in 3–4 yr.

The low water levels on Lake Athabasca do not appear to have been harmful to the lake trout population (*Salvelinus namaycush*). Because they are fall spawners, the critical period for egg survival is over the winter, and it was determined that the drop in winter water levels during the 4-yr period was less than the historical overwinter drop.

It was impossible to assess the effects of the water level changes on the plankton and bottom fauna populations of the delta because of the lack of comparative data during the previous high-water years. Abundant zooplankton were present in the delta, although phytoplankton were scarce. There was also a low standing crop of bottom invertebrates, which could have been due to low water conditions, although it is believed that the considerable amount of suspended silt, which is characteristic of the larger delta lakes, caused the scarcity of these animals. Zooplankton are food for the goldeye and other fish inhabiting the delta.

This completes the assessment of the downstream effects of filling Williston Lake at the Bennett Dam. What will be the effects of the operational phase with the Bennett Dam and Shrum Generating Station generating power? Two computer programs were written to simulate the impact of future lake levels and of wildlife populations on the Peace–Athabasca delta. One program simulated the flows of the contributing rivers, evaporation and precipitation, and generates water levels for Lake Athabasca and the delta. Simulated flow regimes can be changed from one run of the program to another, and the effect of the Bennett Dam and the natural regime can be simulated for the future if the assumption is made that the future flows will be similar to those of the past.

If the natural regime is plotted alongside the modified regime, the difference in these hydrographs represents the changes in the regime that would have resulted had the Bennett Dam been in operation since 1960. The difference in regimes is due to the operating plans of the Shrum Generating Station which call for the release of flows at a fairly constant rate of about 36,000 cfs throughout the year. Additional spring releases will occur in some years when the reservoir is filled, but even these, when combined with the flows contributed by tributaries downstream, will not be sufficient to prevent a marked departure from the past flow pattern of the Peace River.

The long-term hydrological change will be a 1-ft reduction in the summer levels and a 2-ft reduction in the peak levels. The actual levels will vary considerably as in the past.

The wildlife computer model was written to accept water levels generated from the hydrologic model and to translate the effects of water regime changes into wildlife numbers or habitat changes. Vegetation on the delta was classified into 11 types including water, emergents, mud flat, immature meadow, sedge meadow, grass meadow, low shrub, tall shrub, deciduous forest, coniferous forest, and rock outcrop. Using black and white air photo coverage, a vegetation map was prepared identifying each of these habitat types present in 1970. Area and shoreline length measurements were made from the maps, and these data are read into the computer model and represent a starting point from which to apply rates and directions of habitat changes in response to water level.

Topographic surveys were conducted in the field to determine the vertical positioning of a sample of perched basins on the delta. Depths of the perched basins were recorded, along with the elevation of the various habitat types in them. These data were also fed into the model and were used to prepare a mathematical contour map. Aerial photographs from 1968 and from 1971 were used to determine changes in area of water surface during the period of declining water levels. These percentages were converted to an annual figure and used in the model to calculate shoreline mileage during simulated years when the delta is not flooded.

Vegetation succession on the delta is a complicated phenomenon governed by a variety of processes, the most important being proximity to water. For purposes of incorporating plant succession into the model, the successional trends are considerably simplified. Three types of succession were considered: succession on exposed lake bottom, succession on meadows existing prior to 1968, both of these under conditions of declining water levels. The third pattern was successional trends occurring under conditions of prolonged flooding. With this information programmed into the model, the program could accept water levels during the growing season for a number of years, and update the type of community that would be expected to occur based on plant succession at a particular point governed by water level changes since 1970.

Also considered in the model was the length of perched basin shoreline that would result each year. Length of shoreline is governed by the amount of flooding which fills the isolated perched basins, minus the evaporation. The computer model keeps track of the shoreline amount present during the various seasons each year.

Water level fluctuations affect not only the habitat of wildlife, but also at certain times of the year, the wildlife populations themselves. The 5-day water level output from the hydrologic model was grouped into five time periods during the year representing intervals of ecological significance. The "ecological year" began at breakup or May 1, with time period one being the month of May, time period two, the month of June, the third time period being July 1–August 14, the fourth being August 15–October 15, and the fifth time period representing the winter period of October 15–April 30. Within these time periods or groups of periods certain critical animal functions can occur, including the nesting season for waterfowl, the fall or spring staging periods, the overwintering period for muskrats, the growing season for the vegetation, and so on. Water level fluctuations within the time periods are also considered important for certain functions. Therefore the maximum level and the minimum level, as well as the average level were fed into the computer for each of the five time periods each year.

The 1971 wildlife populations of muskrat, waterfowl, bison, and moose were entered as starting levels for the populations. Then the model could accept the five water levels for 1 yr, and allow the populations and habitats to change and grow according to the programmed rules of change or survival.

As an example of how animal populations are handled, let us consider muskrats. The model accepts the 1971 population as censused during the study. The sex ratio was assumed to be 1:1 and the model initially uses a spring to fall gain of 14 young per female, or 7 young per adult. But rising water levels during time periods one, two, and three reduce the optima production as follows: If water levels rise less than 1 ft, young muskrat mortality is zero; a 1–2 ft rise causes a mortality of 7.5 %; between 2 and 3 ft the mortality is 15%; between 3 and 4 ft, mortality is 30%, and a rise greater than 4 ft causes a mortality of 50%.

Normal summer mortality of adults is 5% of the population and the mortality is programmed to occur just prior to the breeding season.

The fall population is the sum of the young muskrats remaining plus the adults. The winter population is governed by the carrying capacity for muskrats. It is determined by the amount and depth of emergents flooded. Optimum carrying capacity is defined as 10 muskrats per acre of emergents. Winter mortality occurs in all muskrat populations, and in calculating the carrying capacity, depth of ice and water was considered. For example, if the water depth in the perched basin was 0.6–1.0 ft the percent surviving is equal to 30. Survival is better as depths increase, to a maximum of 70% at depths over 3 ft. Flooded areas less than 0.6 ft deep were not considered to be capable of overwintering muskrats.

The model keeps track of the water levels and the muskrats produced for each area, and totals the population at the end of each year. Trapping can be simulated, and if trapping is specified, it is assumed to occur in the spring, acting upon the March population and reducing it by 50% just prior to the breeding season. The simulated trapping was kept relatively simple and density independent because not enough was known to assign a density-dependent relationship to the trapping rate.

For each of the other animal species the most pertinent factors were used to update the population growth within the computer model. The model was used to compare the natural regime with the one to be expected under full operation of the Bennett Dam. Most comparative runs were made using a simulated sequence of 35 yr of water levels starting with 1971. There is no way of predicting any exact sequence of years, therefore several runs were made to simulate several possible combinations of water level events for the future. Each gives a different answer because each sequence of events affects plant succession and wildlife production in a different way. But by

using a number of paired runs it was possible to arrive at a general prediction of the impact of the modified regime on future wildlife populations.

The results indicate that the modified regime under operation of the Bennett Dam is expected to decrease shoreline miles of perched basins by about 50–55% in the future. Duck production under the modified regime will be decreased by approximately 20–25%. It is predicted that the overall winter carrying capacity for muskrats on the delta will decrease 40–55% and the actual fall populations will decrease in the order of 40–65%. These changes can be expected because of the average reduction in water levels on the delta of approximately 1 ft during the growing season, thus affecting plant succession, and because of a reduction in the amplitude of flooding, which reduces the number of filled perched basins.

Fish populations were not included in the model because of lack of quantitative information. The lower water levels, however, will reduce the chances of successful spring migrations into the spawning lakes. Walleye in particular might be affected because they return to Richardson Lake, a lake whose outlet is sometimes blocked by ice. The goldeye population is not expected to be adversely affected by the lower water levels because the spring levels in the access rivers will be adequate. Lower water levels in the delta, however, will bring less frequent flooding of the larger lakes, and the amounts of organic detritus normally brought in by flooding will decrease. The zooplankton, the major food source for goldeye, could be affected by these regime changes.

The impact of these changes is extensive, and a major part of the delta is located in Wood Buffalo Park. The Peace–Athabasca delta is the only delta within the Canadian parks system. Furthermore, the delta is a key link on the four North American flyways for migratory birds. And in addition, the reduced muskrat populations and possible reduced walleye populations will hamper local trapping and possibly fishing, thereby aggravating the already serious unemployment and low income problems in Fort Chipewyan. Thus the project group turned to an assessment of remedial alternatives designed to restore the delta to its previously productive state.

A number of control dams were considered on several outlet channels to Lake Athabasca, and also on the Slave River. Three types of structures were considered — a fixed-crest weir, a rock constriction and a gated control. Gated controls, if properly managed, could almost completely restore the previous regime. The disadvantages include high cost, perpetual management, and the possible reluctance of man to manipulate waters to duplicate extreme natural events within a park. To the ecologist, extreme events are just as important in maintaining a natural environment as are average ones, but it might become difficult or controversial to permit a flood to destroy waterfowl or muskrat nests, to drown bison or to kill meadows, if the manager has the power to avoid this. National parks have been set aside to allow today's and tomorrow's generations to visit and see nature in an unmanaged state. The gated control was thus ruled out as the project group believes that the degree of refinement necessary to achieve restoration of the natural ecological regime can be accomplished without it. Of the two potential sites examined, the Slave River site offers the best fit to the natural regime, but the Slave River is an extremely large river and would very likely cause ice problems by jamming the river during spring. The Slave is a navigational route and therefore a navigation lock would be necessary. A fishway would also have to be installed, and fishways are not always successful.

The project group finally selected the Rochers River site for a fixed-crest control structure even though it would not completely restore the amplitude in the summer peaks, but would restore the average summer level on the lake and the delta. Its advantages were that it would not interfere with fish migration because there is an alternate and more frequented route for fish to gain access to the delta, and the Rochers site would result in less ice problems than would the Slave site. The structure would also be built at a cost of approximately $1 million, as opposed to $13 million for the Slave River site, and this Rochers site would not block navigation because an alternate route exists. The project group recommended that a fixed-crest weir be built on the Rochers River to compensate for the decline in lake levels due to the changed regime caused by the Bennett Dam.

It was also recognized that during an 18-mo study, many unanswered questions about hydrology, ecology, water quality and so on remained, and that the possibility exists that the recommended structure will not achieve its stated objective. Therefore the project group also recommended that a resource monitoring program be initiated to evaluate the effectiveness of the proposed structure on restoring the levels of Lake Athabasca and the delta. It was recommended that this program be continued until such time as the weir has proved adequate.

The complete findings of the project group are contained in a Technical Report, Peace–Athabasca Delta Project, and in three volumes of appendices. Copies are available from Information Canada, 171 Slater Street, Ottawa, Ont.

An Interdisciplinary Approach to Development of Watershed Simulation Models[1]

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WALTERS, C. 1975. An interdisciplinary approach to development of watershed simulation models. J. Fish. Res. Board Can. 32: 177–195.

A workshop approach for the rapid development of simulation models is described. The key feature of the approach is intimate involvement of resource specialists in the model building process, so that communication between resource disciplines is greatly enhanced. Two watershed models that have been developed in 1-wk workshop meetings are described to show the kinds of factors that can be considered. One model is concerned with small coastal watersheds in the Pacific Northwest, and the other deals with part of the James Bay area, Quebec. Both of these models have helped scientists of Environment Canada identify major information needs that are not being considered in current research and management programs; in particular, little is known about the dynamics of recreational demand.

WALTERS, C. 1975. An interdisciplinary approach to development of watershed simulation models. J. Fish. Res. Board Can. 32: 177–195.

L'auteur décrit comment on peut utiliser la méthode de la réunion de travail pour élaborer rapidement des modèles simulateurs de bassins hydrographiques. Le point central de la méthode consiste à impliquer intimement les spécialistes de la ressource dans le processus d'élaboration des modèles, de façon à faciliter le plus possible la communication entre les différentes disciplines. Comme exemple des facteurs qui peuvent être étudiés, l'auteur décrit deux modèles de bassins mis au point au cours de réunions de travail d'une semaine chacune. Un modèle se rapporte à de petits bassins côtiers du Pacifique Nord-Ouest et l'autre à la région de la baie James, au Québec. Ces deux modèles ont permis aux scientifiques d'Environnement Canada d'identifier les domaines dans lesquels on a besoin de plus de connaissances et qui ne sont pas couverts par les programmes de recherche et d'aménagement en cours; en particulier, on ne connaît que très peu de la dynamique de la demande au domaine récréatif.

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HYDROLOGIC simulation models are now widely applied for investigation of short and long-term flow patterns in watershed systems. However, there is a need to see if such models can be connected to biological and economic predictions to provide a comprehensive picture of the watershed as a management unit. Considering present knowledge of ecological interactions in watersheds, it would be unreasonable to expect any comprehensive model to have high predictive power. However, a major problem in watershed management is to ensure communication between the research and management disciplines (e.g. forestry and fisheries) that are responsible for various phases of program development. Too often we find watershed investigations conducted as a series of fragmentary studies that have little relevance to one another. The exercise of developing a simulation model, by providing a common language and concrete focus for discussion, can provide specialists with a unique opportunity to present their mutual information needs clearly and precisely. For example, the fisheries biologist cannot be content with a vague statement about his need for water flow data; he must instead show exactly what numbers, in terms of spatial and temporal resolution, can be used in his fisheries predictions.

Almost always the exercise of model building sugests major information needs that would not otherwise be recognized, both at the interface between disciplines and within particular areas of study. It is only after some preliminary but intensive modelling work has identified these information gaps that we can expect the kind of data to be collected that will eventually lead to useful predictive models. It is usually supposed that data collection must precede modelling; the fallacy of this argument becomes apparent when one notes that the investigator must have some model in mind, usually subjective and not clearly articulated, to guide any of his data collection.

Perhaps the most difficult task in watershed management simulation is to ensure that resource

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specialists, who are usually not trained in modelling, are intimately involved in model building and testing. Whatever mathematical and simulation framework that is considered appropriate must incorporate the ideas and information of such specialists, and must further provide feedback about the consequences of these ideas when incorporated into an overall prediction of system change.

This paper describes a workshop approach to interdisciplinary modelling and outlines two watershed models that have been developed by resource specialists using the approach. Each of these models was conceptualized and implemented in a 5-day workshop meeting involving 15–20 scientists from Environment Canada and 5–7 model builders from The University of British Columbia. One model is concerned primarily with interactions between forestry, fisheries, and recreation activities in small coastal watersheds of the Pacific Northwest; scientists from several Environment Canada laboratories and offices in British Columbia were involved in its development. The second model tries to examine potential impacts of hydroelectric development in the La Grande River basin, James Bay area, Quebec; most of the personnel involved in its development were from the Environment Canada headquarters management staff in Ottawa. We choose these examples as extremes to show that the workshop approach can be applied to a wide variety of problems and personnel situations, from very narrow and research-oriented to very broad and policy-oriented.

Tactics of Workshop Organization

Most of the time required to develop a typical simulation model is tied up in computer programming, juggling data, and achieving communication between the model builder and the subject matter expert. Identification of variables, relationships, and appropriate mathematical format usually proceeds very quickly. A small group of programmer-modellers, working with purely hypothetical data drawn out of the air as needed, can put together a very respectably complex model in a few days. Our modelling workshops are essentially attempts to bring together the communication and implementation phases of modelling into a single, efficient time package.

Because computer programs require the use of many arbitrary definitions and conventions that must be chosen by the programmer, it has proven unwise to have too many people involved in model implementation. We have found it most efficient to have one programmer for each major subsystem under consideration, along with a maximum of four subject matter specialists. Workshops with more than six groups of this kind become unmanageable. It is critical that each programmer have a reasonable grasp of the subject matter and jargon of the specialists with whom he will deal. Programmers with training only in mathematics or computer science are often less than useless, because they tend to introduce still another confusion jargon. Our best modellers have been resource students who have picked up a bit of programming on their own or through one or two undergraduate courses. It is essential that the programmer and the participants view the mathematical and programming work as technical translation, rather than as a fundamental addition to the conceptual understanding of the problem.

When programmers with some model building experience are used, it is not important that the participants have any special background training. The only requirement for effective participation is a willingness to be a bit simpleminded and general in looking at each part of the system. Quantitative models can capture only some simplified features of any system, and we have found that many specialists find it impossible to think about simpler rather than more complex ways to view their parts of the system. In other words, most people find it easier to take a system apart into smaller conceptual pieces; putting the pieces together into some simplified overview is much more painful, because it requires that the specialists exercise some judgment about the relative importance of each piece. About all that can be said in general is that the best workshop participants are usually those people who have had to deal with practical problems where judicious simplification is usually necessary to get any answer at all.

During most workshops it is important to have experienced model builders who can carefully avoid the use of mathematical jargon. Participants have no way of judging the importance of unfamiliar terms, so they often believe that the modeller has said something profound when he uses a term like "matrix" instead of "table." Such a slip can have serious consequences if it leads the participant, who usually has the best conceptual understanding of the system, to think that the modeller has some special understanding of what is happening; a lot of models are filled with elegant but irrelevant mathematics. It is critical that the participant understands exactly how his ideas are being translated for the computer. The business of translation makes the model builder's job harder, but there is little about model building that cannot be stated in everyday terms with a bit of thought.

We have used a variety of computer systems, ranging from an IBM 1130 (8k, card reader, and printer) through an IBM 370-155 with remote batch processing. The best systems we have found so far have been those with interactive terminal capability and special programmed packages for input and output (Hilborn 1973). The interactive terminal systems allow programmers to type models directly onto disk storage, with instant access for debugging and test runs; programming time can be cut to an order of magnitude less than would be required with the usual batch processing. Also, interactive systems make it much easier to do repeated runs of a model as gaming exercises.

We have held over a dozen model building workshops in the past 3 yr, varying in length from 2 days to 1 yr (with weekly meetings). For most purposes, the optimum seems to be one or more 4–5 day long sessions, separated by not more than 2 mo. Irregular short meetings (a few hours) spaced more than a week apart are almost sure to be unsuccessful. One compromise that we have used for particularly difficult problems has been to hold two 1-wk sessions a month apart. The model is conceptualized during the first session, data juggling and programming are done between the sessions, and the second session is devoted to testing, modification, and gaming. The workshop organization that we have found most useful is shown below (for a typical 5-day session as used with each of the watershed models):

Introductory lectures, demonstrations (1 day)	→	Identification of variables and linkages between subsystems (1 day)	→	Submodel development, small groups (2 days)	→	Testing and gaming, overall model (1 day)

The introductory lectures and demonstrations are fairly straightforward and usually involve the complete development and implementation of a very simple (2–5 variable) model.

The critical time is during the second day, when the general problem for the meeting is made explicit and is divided into manageable components. It is here that the general level of abstraction of the model is decided by identifying the list of state variables to be simulated, and it is made clear exactly what information must be generated about each component of the system in order to simulate the other components. The most common problem encountered at this stage is that specialists want to build unnecessarily detailed models for their own subsystems; when serious conflicts do arise, we simply attempt to sketch out two alternative submodels, one simple and one detailed, and try to decide how their behavior will differ. The more detailed alternative is selected only if it appears that the behavior of the overall system model will be affected.

It is emphasized that the output of the second workshop day must consist of a list, for each major subsystem, of the variables that must be simulated by that subsystem modelling group for use in the other submodels. It is left completely up to each subsystem group to decide what other variables to consider, knowing that their central objective is to generate these linkage variables. The second day is a particularly valuable part of the overall workshop, since here most of the communication takes place between specialists of different disciplines.

After the identification session, the workshop programmers meet and decide on computer variable names and other programming conventions. Each submodel can then be programmed and run alone with dummy values for input from other submodels, and any combination of submodels can be tacked together quickly. Dummy values can be replaced by dynamic calculations as other submodels become available.

The participants then divide into smaller groups, each led by a programmer–modeller, to develop the submodels. The emphasis in these sessions is on laying out the basic components of change of each variable assigned to the subgroup, and on graphical description of functional relationships between change and other variables being simulated. For example, the first step in developing a fish population model would be to state the basic components of population change as "new population = old population + recruitment + growth − natural mortality − harvest." Next, each component of change would be related graphically to other factors being considered. No attempt is made to develop elegant mathematical formulae for the functional relationship; finding an equation of the right shape is considered the programmer's task. Also, we defer questions of data availability and parameter estimates until after the overall conceptual framework has been laid out with graphs and flow charts; otherwise the group invariably gets sidetracked on questions (often trivial) of data acquisition. It is usually necessary to reiterate, frequently, the idea that a major goal of the exercise is to identify as many information gaps as possible, and to assign some relative importance (sensitivity) to each.

The business of programming, keypunching, and debugging each submodel is usually left entirely to the group programmer while the participants assemble relevant data. The participants work through the completed program, with the help of the programmer, to ensure that he has

translated their conceptualization as intended. Problems can arise at this stage if the programmer encounters a particularly difficult coding problem and finds that he must use some additional simplifying assumptions in order to complete his task within the time available. Such coding problems are most commonly associated with the representation of spatial interactions in the system.

After the groups have the various submodels working separately and producing reasonable answers, the programmers sit down as a group and put together the overall system model. Almost invariably, errors arise through confusion about variable names, units of measurement, and extent of information exchanged between submodels. Formulation of the submodels has usually indicated that other variables need to be generated besides the ones originally agreed upon; decisions about these variables are made by informal discussion between subgroups, and usually a few of these variables are overlooked in the rush. The overall process of interfacing submodels usually takes about one full evening, if each submodel is already working properly.

The final day of testing and playing with the overall model is usually a confusing time. The typical model has many variables and several hundred parameters; also each submodel can usually accept several management interventions. The assortment of possible tests and analyses is staggering. To make things simpler, each subgroup is asked to itemize a few key runs that test sensitivity to parameters and management interventions. These basic runs are made first, and further runs are decided upon by discussion among the participants.

A major problem during the testing session is to ensure that the model output is both comprehensible and comprehensive. Tables of numbers are very difficult to read, so graphical output is necessary. When many variables are graphed or displayed for each run, the process of interpreting the results can be time-consuming and confusing. Therefore, each group is asked to generate one or two key indicators for the performance of its submodel, such as a general index of population size, an index to economic well-being, or the like.

The workshop closes with an evaluation session aimed at identifying key areas for future research work and obvious implications of the model for management practice. Only at this point is emphasis placed on the disparity between the kinds of data available and those needed for the model. We have found it important that this overall evaluation not be deferred until weeks or months after the session, since participants always seem to quickly forget most of the ideas that are brought out by the modelling exercise.

The Silt Creek Exercise

The economy of western Canada is partly dependent on three major resource activities: forestry, salmon fisheries, and outdoor recreation. These activities are often centered around small coastal watersheds like the hypothetical Silt Creek shown in Fig. 1. Environment Canada devotes considerable research effort to forest management practices and is responsible for coastal fisheries management. Recently a large research program was initiated by the Fisheries Research Board to explore impacts of forest management on salmon production in a small watershed (Carnation Creek). However, there has been rather poor communication between the forest and fisheries agencies; the Silt Creek Workshop was intended to bring these disciplines together for a look at mutual research needs and possible management trade-offs for small watershed systems in general. A hypothetical area was chosen to help participants focus their attention on conceptual problems rather than routine questions of data acquisition. The workshop ran for 5 days, with 20 participants from all of the Environment Canada offices in B.C.

A first step in the workshop was to identify major areas of disciplinary concern (submodels) and the information that would have to be transmitted between these areas in order to simulate watershed behavior over long periods (15–100 yr). The result of this effort was an information table (Table 1) showing exactly what each discipline-oriented submodel was expected to produce. The discussions leading to Table 1 also made it possible to agree on the degree of spatial resolution needed to adequately represent local management activities and transport of materials; it was decided to treat the watershed as a series of 160-acre parcels (Fig. 1), each homogeneous with respect to forest stand conditions, runoff characteristics, and stream condition. It was made clear that the submodels had to represent: 1) the dynamics of individual areas in terms of a single general set of calculations that could be repeated every simulated year for every area, with different starting values, and 2) connections between areas in terms of forest seed dispersal, water movement, and the like.

The submodels for each disciplinary area were then developed and tested by small groups of participants. These submodels are listed as the row and column headings in Table 1; the following

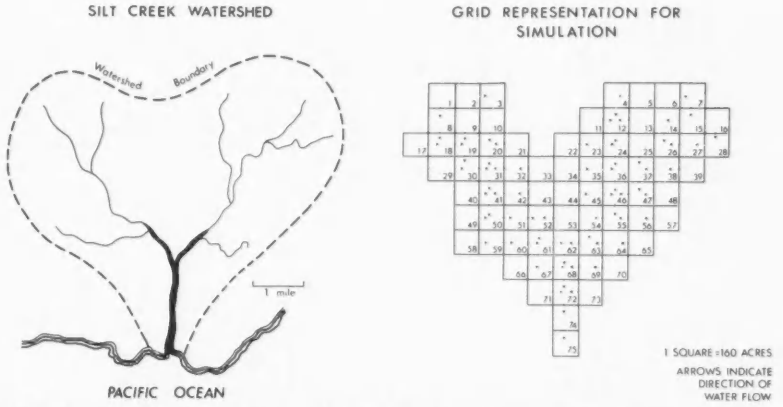

FIG. 1. The Silt Creek Watershed and its abstract representation in the simulation model. Each grid area is assumed to have homogeneous forest type and stream conditions.

paragraphs give an overview of the factors and relationship considered in each. The intent of this overview is to show the kinds of factors that can be considered in a short workshop exercise; the description should not be considered a definitive outline for watershed models in general.

FOREST MANAGEMENT

The forestry submodel is divided into two major sets of calculations — for production and for utilization. The production section is essentially a stand development model; for each 160-acre area in the watershed, it calculates changes in wood volume present as a function of tree age (since last logging), management practice, and forest site quality (areas near the mouth of the watershed were assessed to have the highest site). For any simulation run, management practice is defined as a series of yes or no decisions concerning planting, stand thinning, and fertilization. A different volume production function is used depending on which decisions are taken. The stand age and volume estimates are used to generate indices of overall forest condition for each area (e.g. slash, regenerating, mature), which are used in the hydrology, fisheries, and recreation demand submodels.

The forest utilization calculations are essentially a bookkeeping system to keep track of the location, timing, and pollution impact of logging operations. Any logging pattern across the watershed over time can be established by intervention before a simulation run. When an area is logged, its stand age and volume are set to 0. Depending on another intervention, silt, nutrients, and stream slash blockages may be created for use in other submodels. The silt input and blockages to fish passage are assumed to persist for several years after logging. A road building pattern, represented in the computer by a time-varying access code for each 160-acre area, is also established by intervention. Road construction and presence are assumed to result in silty loads in adjacent streams, independent of actual logging operations.

Some forestry problems were not considered at all — for example, fire and insect damage or intensive tree farming activities. Thus the forestry submodel produces an optimistic picture of natural productivity. Treated as a black box, it has as its main inputs patterns in space and time of forest management, and as output it produces patterns of forest yield and pollution.

HYDROLOGIC CONDITIONS AND WATER QUALITY

Water flow patterns and water quality (silt, nutrients, coliform count) are simulated on a monthly basis in order to provide seasonal extreme conditions for the fishery submodel. Each 160-acre area is assumed to have a monthly contribution to runoff dependent on its forest stand condition. Higher winter and lower summer runoffs are associated with recently logged areas. No attempt is made to relate runoff explicitly to precipitation, ground water movement, and evapotranspiration; runoff estimates used in the simulation are assumed to be the result of these processes. Monthly runoffs are accumulated downstream from area to area to give an overall picture of stream flow for each month in each area. The computational bookkeeping for down-

TABLE 1. Information transfers in the Silt Creek watershed model. Each row-column position shows variables simulated by the row submodel for use in the column submodel.

	To or using submodel					
	Water flow and quality	Salmon population	Inshore marine environment	Forest production and management	Recreational land use	Environmental and economic impact
Water flow and quality	Monthly water flow by area, pollutant transport	1. Summer and winter flows by area 2. Silt and nutrient concentrations 3. Stream bed silt load	1. Seasonal flow at river mouth 2. Silt, coliform and nutrient concentration at stream mouth		1. Summer concentrations of silt, coliform, nutrients	1. Summer concentrations of silt, coliform nutrients
Salmon population		Population dynamics in response to habitat and harvesting			1. Annual catch and catch per effort in spawning stream	1. Annual commercial catch
Inshore marine environment			Production of oysters in response to habitat			1. Annual oyster production saleability
Forest production and management	1. Stand conditions (slash, regenerating, mature) 2. Silt and nutrient inputs per area 3. Buffer strip width	1. Location of slash blockages to fish passage 2. Stream bank vegetation (yes or no)		Spatial patterns of tree production and utilization	1. Stand conditions by area 2. Ownership 3. Road access pattern	1. Annual volume cut 2. Annual road miles constructed
Recreational land use	1. Nutrient, silt, and coliform inputs by area	1. Man-days of salmon fishing in stream		1. Land area held for cabin use	Demands for cabin lots and other recreation	1. Number of cabins constructed 2. Total man-days of
Environmental and economic impacts	Fisheries and forestry operating levels set by intervention				1. External demand for land	Summary of benefits and costs of resource use

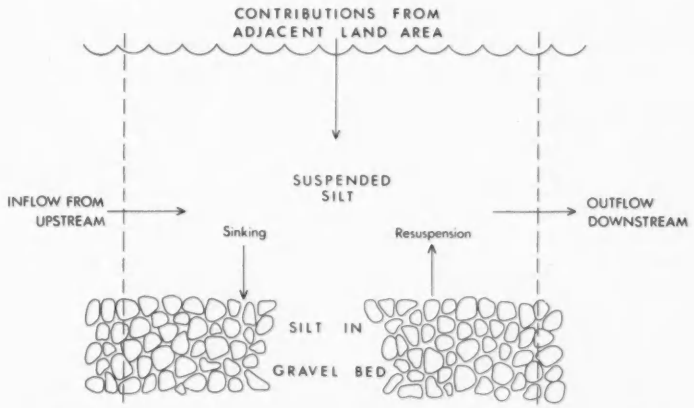

FIG. 2. Dynamic interactions considered in the Silt transport assumptions are critical in assessing interactions between forestry and fisheries management practices.

stream calculations is simplified by assuming that each area has one and only one area to which it delivers water.

Silt, coliform, and nutrient inputs to each area are estimated in the forestry and recreation submodels. The hydrology submodel dilutes these inputs, based on water flow, and moves them downstream. Nutrients and coliform count are assumed to be conserved (not used up or degraded) as they move down the watershed, but silt concentrations may change due to sedimentation and resuspension. The basic dynamics assumed for silt transport are shown in Fig. 2. The key feature of these calculations is consideration of accumulation and later release of silt by the stream gravel bed; release from the bed may result in silty conditions for several years after any pollution source has been stopped.

SALMON POPULATION DYNAMICS AND HARVEST

Though several salmonid species would normally occupy an area like Silt Creek, we chose to simulate only coho salmon (*Oncorhynchus kisutch*) as a typical example or indicator population. One problem that appeared immediately during the development of this submodel is that salmon may home to very specific areas within the watershed for spawning; thus we chose to treat the fish in each stream section defined by a 160-acre area as a separate population (with potential for straying and dispersal to other sections).

The life cycle of fish is treated as a series of stanzas: egg, fry, smolt, first ocean year, second ocean year, and spawning. Thus the state of the population in the model is characterized by a large table of population numbers, where the rows represent stream sections (defined by 160-acre areas) and the columns represent stanzas. Survival rate in freshwater stanzas is assumed to be a function of stream flow, silt and nutrient loads, population density, and stream bank cover conditions (estimated from forest conditions). Dispersal is assumed to occur in the fry and smolt stages, so that juvenile fish are spread evenly over all accessible portions of the stream network. Most adults are assumed to home to the section where they spend the fry stage, but a small fraction are distributed across all available sections to simulate straying. Logging operations may result in blocks to fish passage; adults unable to reach their home sections are distributed over all accessible sections in proportion to relative water flow in these sections.

Beyond a basic mortality rate, survival in the ocean and spawning stanzas is assumed to be affected only by fishing. Ocean harvest rates (commercial plus recreational) are chosen by intervention before each simulation run. Recreational fishing effort for spawners moving upstream is estimated each year in the recreation submodel; catch is related to this effort with a standard fisheries catch curve (exponential function).

INSHORE MARINE PRODUCTIVITY

It was assumed that Silt Creek empties directly into a protected area of the Pacific Ocean, such as the Strait of Georgia. Pollutant materials (silt, coliform bacteria) from the stream could affect

productivity of the adjacent marine environment, particularly for benthic organisms. As in the fishery submodel, we chose to look at only one indicator species, the Japanese oyster. The marine productivity submodel attempts to predict silt and coliform concentrations along the shoreline adjacent to the stream mouth, and to relate these concentrations to potential commercial production of oysters.

No attempt was made to develop a comprehensive hydrodynamic model to predict transport patterns of materials in the ocean. Instead, it was simply assumed that water movement is nearly random, so that average concentrations decrease as the inverse square of distance from the stream mouth. Parameters for rates of decrease were chosen so as to represent typical rates of silt settling and coliform death as observed in empirical studies in waters along the B.C. coast. Silt is assumed to affect oysters by decreasing spat settling success and growth rate. Overall potential production rates for representative areas along the shoreline are calculated from spat success and growth rate, under the optimistic assumption that spat will be abundant every year unless silt is limiting. Coliform counts are assumed to affect only the marketability of the oysters; maximum permissible coliform levels are set by intervention before each simulation run.

Recreational Land Use

The fisheries, forestry, and water submodels generate an overall picture of resource conditions across the watershed. The recreation submodel attempts to predict how these resources will be used as a function of environmental quality and land ownership policy. For any simulation run, part or all of the watershed may be placed in public ownership (parkland) before or after logging. Each 160-acre area of this public land is assumed to receive recreational use (man days of hiking, hunting, and fishing) in proportion to its accessibility and perceived environmental quality. Accessibility is assumed to be inversely proportional to distance from the nearest logging road. Perceived environmental quality is measured as a 0–1 index; virgin forest areas with clear water and many fish are given index values of 1 while areas deficient in any of these characteristics are given smaller index values.

Subdivision into recreational lots and potential cabin development is assumed to occur on all non-park land in the watershed except that designated for forest management. Marine waterfront lands near the stream mouth are assumed to be fully developed when the simulation begins. The rate and spatial pattern of inland lot development are assumed to depend on environmental quality (as represented by the combined forest–water–fish index), on road access, and on the degree of crowding as development proceeds. In each simulated year, the model first estimates a potential demand for lots (total number of lots that could be sold); this potential demand can be varied over time by setting a growth rate parameter before any simulation run. A gravity model is used to allocate demand over available lots, where the gravity weighting for each lot is a function of access, quality, and number of lots already developed in the same 160-acre area. The lots with highest gravity weighting are developed first.

Cabin construction is assumed to result in silt input to adjacent stream sections, and recreational use-days are assumed to result in some input of nutrients and coliform count to streams. Cabin use is assumed to be more polluting than camping or day use. The pollutant loadings due to recreation for each 160-acre area are added to loadings due to forestry operations to give an overall input picture that is used by the hydrology–water quality submodel.

Since we expect potential demand to be largely a function of conditions (population, alternative recreation areas) outside the watershed, unconditional predictions from the recreation submodel are not likely to be meaningful. Its predictions are useful only to the extent that they indicate some broad response patterns and general impact problems that might arise for some different demand patterns that could occur.

Environmental Quality and Economic Impacts

A final submodel in the Silt Creek exercise was devoted to the representation of regional economic impacts of watershed development, and to generation of overall indicators of environmental quality. This submodel is essentially a bookkeeping system with no dynamic relationships or feedbacks to other submodels. It takes information on rates of return from logging, fishing, oyster farming, and recreational development and compares these rates to operating and capital costs for each industry; the result is a measure of net economic return. The total number of jobs in primary resource industries is also generated.

The environmental quality indicator mentioned above (recreation submodel) is estimated for each 160-acre area in this submodel. There is also an indicator for overall quality of land (area of mature forest divided by total area) and for water quality (total salmon run divided by the

run size expected under pristine conditions). These indicators were designed to give a general feel for how the Silt Creek area would look over time, under alternative management strategies; they are not meant to be absolute measures of quality.

Results of the Silt Creek Exercise

It must be remembered that this Silt Creek model was developed over a very short period of time (3 days), so many factors were necessarily omitted or overlooked. Nevertheless, the model gives a rather more comprehensive picture of watershed problems than we expect is used as the basis for most management decisions today. Most participants in the workshop indicated that it gave them a valuable chance to look at the problems and assumptions of other disciplines, and several indicated that it had helped identify research areas where critical information is lacking.

Some sample results from the overall model are shown in Fig. 3, to indicate how it might be used to compare alternative management strategies. Most participants felt that test runs such as these made during the workshop were not particularly valuable, since there was little time to develop parameter estimates. Interactions between the submodels resulted in few really surprising predictions of overall system behavior, but Fig. 3 shows some results that had not been anticipated by the participants.

In runs A and B Fig. 3, for example, the model predicted that there should be no simple relationship between stream deterioration due to logging and changes in salmon runs; instead of a gradual population decline with worsening conditions, the population shows almost no response until some "resilience limit" is reached. Beyond this limit, the population declines catastrophically without producing any clear warning signs that would be detected with appropriate biological monitoring. Other test runs with the model suggest that this general response pattern will occur for about all reasonable parameter estimates. The basic reason for the pattern is that salmon runs normally contain a large excess of spawners relative to space available in the stream for egg deposition and rearing of young; this excess is usually not reflected in future population sizes, except when conditions for the average spawning fish become very poor.

A second interesting prediction of the model can be seen by comparing the environmental quality index plots in runs B and C in Fig. 3. Though the usual cut-and-go logging tactics result in a severe short-term decline in environmental quality, the long-term picture is not so bad. On the other hand, integrated multiple use with only the sustainable logging cut taken each year (supposedly the ideal for B.C.) results in lowered environmental quality all the time; clear-cut areas and some stream pollution are always present. Though there may be other ecological interactions not considered in the model that make rapid cutting a poor policy, the suggestion is clear that we need to take a hard look at the apparent benefits of multiple use management.

It is instructive to itemize a few of the data gaps that were identified while constructing the model, to demonstrate that models do not require peculiar kinds of data that are really not needed to make management decisions. First, it was obvious that there is very little data on the quantities of silt and nutrient that can be expected to run off a logged area, given different logging practices; we had to estimate these loadings from crude data on changes in soil depth collected in erosion studies. Second, there is little empirical understanding of silt transport into and from gravel beds, especially in relation to freshet runoff conditions. Finally, we were surprised to see that no one knows how flexible salmon are in choosing new spawning areas when homing is impossible due to slash blockage or when silt conditions would prevent successful egg hatching. It is not even possible with existing data to answer crude questions like: suppose half of the watershed is blocked off; will fish homing to this area spawn in the other half of the system? It was depressing to see that questions like this had not been identified as important, and some answers obtained, a long time ago.

James Bay Model

In contrast to the Silt Creek exercise, the James Bay Workshop was geared to a real and pressing resource problem — the La Grande River basin emptying into James Bay, that will involve millions of dollars in impact studies by various resource agencies and the livelihoods of several thousand people. The La Grande area is scheduled for a large hydroelectric development (Fig. 4) over the next decade. The area supports an Indian population of 1500, and has great potential as a recreation area especially for people from Montreal. Our workshop was an attempt to involve high level policy makers as well as field researchers (20 participants in all) in an integrated look at development impact and also long-range management of the area. An immediate goal was to see if Environment Canada should modify its existing plans for impact

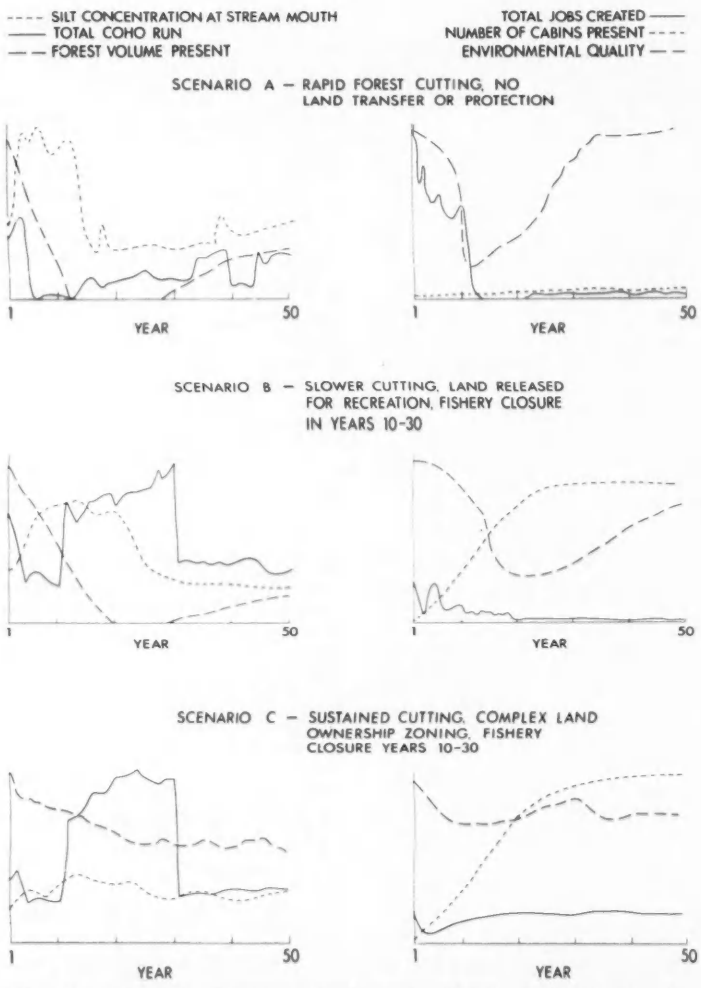
SILT CONCENTRATION AT STREAM MOUTH
TOTAL COHO RUN
FOREST VOLUME PRESENT
TOTAL JOBS CREATED
NUMBER OF CABINS PRESENT
ENVIRONMENTAL QUALITY
SCENARIO A – RAPID FOREST CUTTING, NO LAND TRANSFER OR PROTECTION
1
YEAR
50
SCENARIO B – SLOWER CUTTING, LAND RELEASED FOR RECREATION, FISHERY CLOSURE IN YEARS 10-30
SCENARIO C – SUSTAINED CUTTING, COMPLEX LAND OWNERSHIP ZONING, FISHERY CLOSURE YEARS 10-30

FIG. 3. Typical simulation results from the Silt Creek Model, showing how it can be used to compare alternative management strategies. Only relative values over time for selected variables are shown, to emphasize that absolute quantitative predictions from such models are likely to be very misleading.

studies. Again, we did not expect to produce any solid predictions in the 5-day meeting.

We began the James Bay exercise by identifying a basic set of specific predictions that we would expect the model to handle; this was a tactic for helping to identify problems and questions of interest to Environment Canada. First, it was decided that the model must represent the time course of broad impact on land area, water coverage, and shoreline of the hydroelectric dams and diversions. This is essentially a data summary and bookkeeping problem. Second, we hoped to show the overall biotic response over time to these gross changes; it was expected that the development will destroy habitat for some organisms, but improve conditions for others. Third, it was expected that hydroelectric development will alter the temporal stability of aquatic and shoreline environments by reducing variation in water flows. The model was expected to represent effects

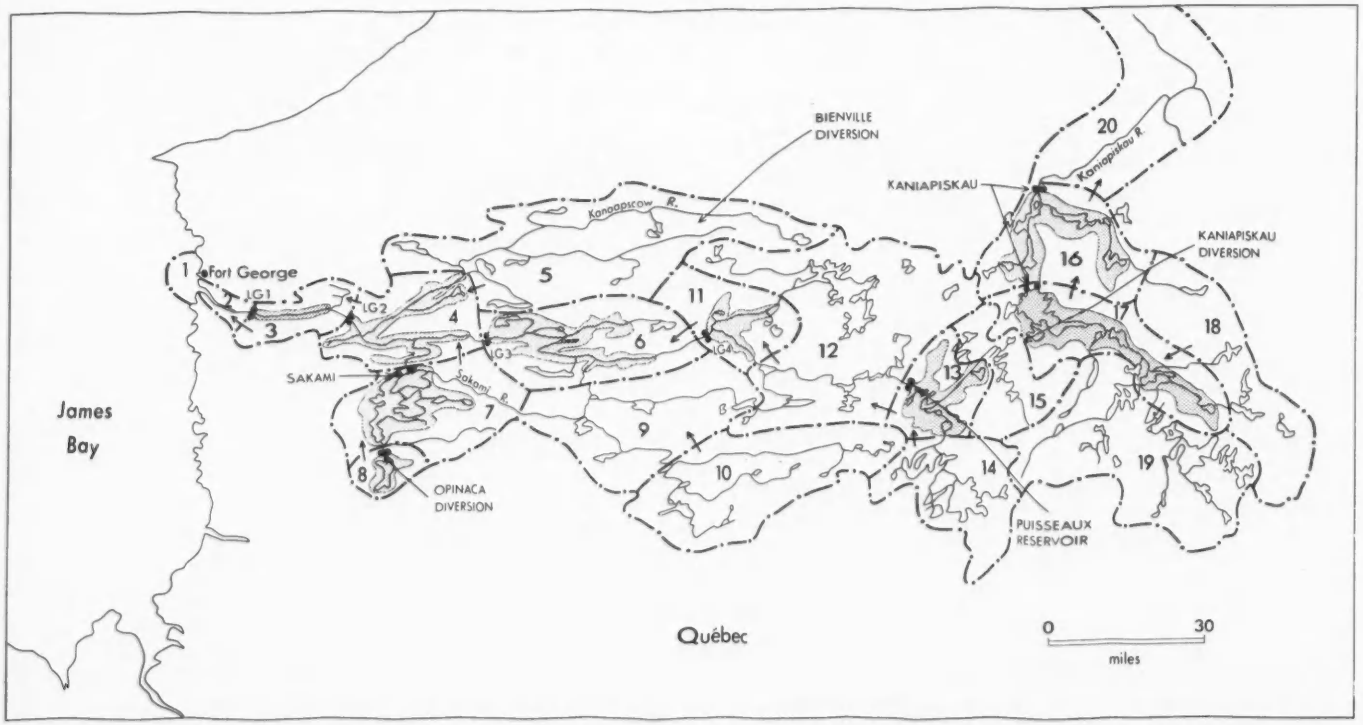

FIG. 4. The La Grande River basin of the James Bay area, showing subareas considered homogeneous in the simulation model (dotted lines), major development sites (light arrows and double dots), patterns of water flow (heavy arrows), and areas to be flooded (stippled).

of this stabilization on vegetation, fish, and wildlife. Fourth, construction and maintenance activities are likely to generate various water pollutants, especially silt. The model was expected to represent the spatial and temporal distribution and dispersal of these materials, and give some prediction of biotic impacts for at least extreme conditions. Finally, development will dramatically alter accessibility of the area, which may result in greatly increased human activity. The model was to represent the general impact of increased exploitation on animal populations of the area.

The identification of these problem areas led to the subsystem breakdown and information transfer scheme shown in Table 2. System components missing from this table include the marine environment and the atmosphere. Hydroelectric development is expected to alter marine conditions, especially winter ice patterns, and there is also the possibility of climatic changes. Meaningful predictions concerning these questions would require the development of very specialized and complex spatial models, which we decided were beyond the scope of a workshop session. Along with the information table, it was necessary to decide on a system for representing spatial patterns; as shown in Fig. 4, we decided to divide the La Grande area into a series of irregular land units, with each unit containing no more than one component of the hydroelectric development (e.g. one dam) and small enough to be considered homogeneous with respect to transportation access and general productivity for wildlife and fish.

We next developed the submodels described in the following sections. Unless otherwise indicated, the calculations were set up to be done separately for each land unit in each simulated year. To save time during the submodelling sessions, we had developed before the workshop a basic data bank of land inventory and ecological information. Also, participants were advised beforehand of particular data problems that we knew would arise, so they were able to provide reasonable parameter estimates in many cases as the submodels were being developed.

Hydrology and Hydroelectric Development

The key submodel developed during the workshop was that concerned with hydrologic conditions in relation to hydroelectric development. It takes as input (before any simulation run) an arbitrary time plan for hydroelectric construction across the land units. This plan is combined with a year-to-year simulation of water runoff patterns to give an overall picture of water storage, seasonal flow rates, and power generation.

Each simulated year begins with an evaluation of seasonal runoff contributions from each land unit. In the absence of dams or divisions, these runoff contributions are simply cumulated downstream to give flow at the major river exit from each land unit. For units receiving development, the model considers three activity phases: construction, filling, and sustained regulation. During the construction phase, the submodel generates only pollutants (silt) below the construction site. During the filling phase, the model generates pollution inputs and reduces flows through the unit to a minimum set by intervention before the simulated run.

For each reservoir site, the model has as input an empirical depth–volume-area covered relationship which is used to regulate filling and to simulate sustained regulation. The regulation calculations consist simply of an attempt to keep outflow at the dam constant, given expected water inflow and constraints on permissible fluctuation of water level (also set by intervention). The flow control patterns are calculated on the assumption that every year will have average flows — in other words that the hydroelectric planners will have no means to forecast runoff conditions. Thus reservoirs are depleted in simulated dry years, and water is wasted in wet years (provided reservoirs are full). Minimum and maximum pool constraints, set by intervention, are used to see that no reservoir is dried completely and that water is added to storage whenever possible.

Power output is estimated as an empirical function of outflow for each reservoir, and this along with silt loadings, road access indices, and land area plus shoreline changes constitute the output to other submodels each simulated year. The construction plan is used in the Land Use Demand Submodel (see below) to provide estimates of recreational impact due to construction workers.

Vegetation and Shoreline Environments

Plant communities in each land unit are represented by a list of acreages of various vegetation types (mudflat, marsh, willow, deciduous forest, coniferous forest). Acreages are moved from one type to another (and lost underwater) depending on water flow and reservoir stage patterns generated in the hydrology submodel. Of particular concern is the shoreline area maintained in mudflat by water fluctuation, and the successional changes in this area that may be permitted by flow control. The vegetation submodel handles this succession around reservoirs very simply by moving acreages into and from

TABLE 2. Information transfers in the James Bay (LaGrande Basin) model. Row-column conventions as in Table 1.

	Using submodel				
	Hydrology and hydroelectric development	Vegetation and shoreline environment	Wildlife populations	Water quality and fisheries	Demand for wildlife and fisheries
Hudrology and hydroelectric development	Water flow regulation, land area changes, construction patterns	1. Area inundated, shoreline mile changes 2. Reservoir depths, area covered and uncovered each year 3. Seasonal water flows	1. Location of active construction sites 2. Seasonal water flows and lake levels	1. Silt, nutrient, and coliform inputs due to construction operations 2. Seasonal water flows, lake levels	1. Construction and operating schedule 2. Road access pattern 3. Jobs available to Indians
Vegetation and shoreline environments	1. Slit inputs along stream and reservoir banks 2. Nutrient input to reservoirs after flooding	Successional dynamics of vegetation, shorelines	1. Acreages in different vegetation types 2. Mudflat area and stream bank successional states	1. Stream bank vegetation condition (present or absent)	1. Width of mudflats along reservoirs 2. General index of vegetation quality
Wildlife populations			Population dynamics in response to habitat and hunting		1. Kills and kills per effort for each species in each land area
Water quality and fisheries			1. Silt concentrations in rivers	Pollutant concentrations and population dynamics	1. Catches and catches per effort by species and area
Demand for wildlife and fisheries		1. Land used for campsites	2. Hunting effort for each species in each area, Indian and recreational	1. Coliform and nitrient inputs due to campers 2. Fishing effort by species and area	Demand by Indians and whites as a function of quality and past returns

the mudflat class according to area change information provided by the hydrology submodel. Mudflat area changes along river banks are estimated from empirical flow-stage-area curves for points near the mouth of each land unit. Vegetation conditions away from the reservoirs and streambanks are assumed to be stable (at climax). The La Grande area is too far north for commercial logging, and forest fires are not a serious problem.

As output to other submodels, the vegetation calculations provide the acreage classes and also some silt pollution estimates. River bank erosion results in some siltation, but a major source is assumed to be bank erosion along newly created reservoirs. Crude estimates of silt contribution from this source were obtained from soil depth data. The amount of shoreline soil available for erosion is stored as a dynamic variable which decreases as the simulation proceeds.

Wildlife Populations

The major animals that may be affected by the development include moose, caribou, beavers, rabbits, puddle and diving ducks, and geese. The model attempts to represent dynamic changes in these major indicator populations for each land unit, as a function of habitat conditions and harvesting demand. It is assumed that there is a carrying capacity or maximum breeding density per unit area for each population on each vegetation type, or when appropriate per mile of shoreline or stream. For example, geese use primarily the mudflat areas, for fall staging, so mudflat acreage is used to estimate capacity for this population. Caribou require woodland areas and marshes for winter range, and estimates were available of their maximum population densities in these habitats.

Annual net population change, in the absence of harvest, is assumed to be a function of spring population size and degree to which the carrying capacity is filled. Population increase per breeding animal is assumed to decrease toward zero as the population nears carrying capacity (logistic growth model). Migration between land units is assumed to be insignificant for the furbearers, but large mammals and waterfowl are assumed to distribute themselves over the area in relation to habitat quality.

Mortality to hunting is estimated from hunting effort (provided by the Demand Submodel described below) and population density. Higher densities result in higher kills per hunter, while increased hunting effort results in lowered success per man. Mathematically, these relationships are represented with an exponential function similar to the catch curve commonly used in fisheries management. Different success parameters are used for Indian subsistence hunting and trapping as opposed to recreational hunting by resident and visiting white people.

Water Quality and Fisheries

The water quality parameters considered in the La Grande area were the same as for the Silt Creek exercise: silt, nutrients, and coliform count. Essentially the same bookkeeping procedures are used to move these materials downstream from any effluent sources (e.g. construction sites). The calculations for each year begin with a picture, provided by other submodels, of input loadings across the watershed. These inputs are diluted according to water flows and expected degradation or settling rates. A special problem in the siltation calculations is the effect of reservoirs and other standing water bodies; the simple assumption is made that the proportion of silt settling out in a water body increases as a negatively accelerated exponential process toward 100% as retention time (volume divided by flow) increases. Thus a reservoir such as LG1 (see Fig. 4) may prevent pollutants due to upstream construction from reaching the lower portions of the watershed.

Four indicator fish populations are considered for the waters of each land unit: Arctic char (*Salvelinus alpinus*), lake trout (*Salvelinus namaycush*), northern trout (*Esox lucius*), and anadromous whitefish. The first three are of potential recreational value, while the whitefish is used extensively by Indians. The structure of each population is represented in the computer as the number of animals in each immature age-group plus the number of mature individuals. Each population is assumed to have specific habitat requirements for spawning (e.g. streams vs. lake shores) and growth. Population changes are related to conditions in these habitats, to population size, and to harvesting effort. For example, pike reproductive rate is related to the shoreline length and water level stability of ponds and lakes; water level fluctuation during spring and summer may result in lowered production. Whitefish spawning success is related to water flow and silt concentrations only in the lower reaches of the La Grande River, and so on.

Harvesting effort is generated in the Demand Submodel and is assumed to be concentrated on adult (mature) fish. This is an optimistic assumption; harvest of juvenile fish may have serious consequences, especially since the number of

years required to reach sexual maturity is high in cold northern waters (e.g. 8–10 yr for lake trout). Fishing success is related to the density of fish and to the number of competing fishermen, as in the wildlife submodel. Though the demand submodel provides a different estimate of overall fishing effort for each land unit, all waters within any unit are assumed to receive equal fishing effort; this again is an optimistic assumption, since overfishing problems may be much more severe in localized areas along roadways.

Demand for Wildlife and Fisheries

Though nonconsumptive tourist use of the La Grande area may become important, we decided to concentrate on consumptive users as the major source of resource management problems. The Demand Submodel tries to predict the amount and spatial distribution of hunting and fishing effort directed at each animal population as a function of accessibility, abundance as measured by past success, and type of restrictive regulation.

The demand calculations in each simulated year begin with an estimation of expected total demand over all land units, by the Indian population and by tourists and construction workers. Indian demand is assumed to be influenced by local population size, which grows at a rate set by intervention, and by the existence of alternative sources of income such as construction jobs. The number of Indians who will give up hunting, trapping, and fishing in favor of construction jobs is assumed to be a function of the abundance of game; the number of jobs offered to Indians is set as a policy intervention. This is a particularly weak area of the model; if many Indians choose to give up hunting and fishing, some animal stocks that are now heavily harvested (e.g. caribou) may actually benefit indirectly from the construction activities. External demand is assumed to be a function of average hunting and fishing success over the whole area, according to the graphical relationship shown in Fig. 5. Demand by construction workers is assumed to be affected in the same way, though it is expected that these workers will have little time for recreation.

Next the submodel distributes overall demand across the land units. Those areas with no road access due to hydroelectric construction receive very low effort relative to accessible areas. Units that have had high hunting or fishing success the previous year receive proportionately more effort. Full knowledge on the part of hunters and fishermen, as to where the best places will be to go, is assumed; thus it is implicitly assumed that people

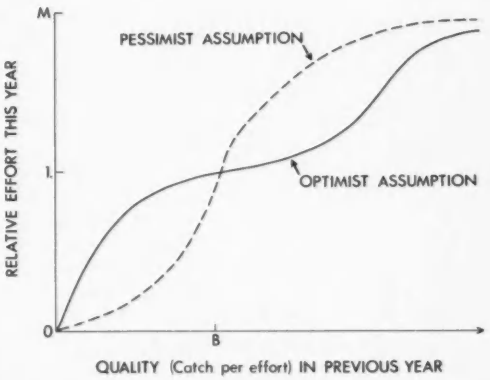

Fig. 5. Example of a troublesome functional relationship in the James Bay Model. Little is known about how recreational demand will respond to changes in quality; the two alternative assumptions shown were tried in different simulation runs. The optimist assumption results in destabilization of population sizes and demand over time.

will explore around the area to find high quality conditions. A series of interventions before any simulation run allow for regulation of demand through closure of units or restriction of total use to campground areas with limited capacities.

From the external demand, construction work, and Indian population estimates, the demand submodel generates nutrient and coliform count inputs to the major river section of each land unit. Initial test runs with the water quality submodel indicated that these inputs may be sufficient to cause problems at Ft. George, where the major Indian community takes its water supply directly from the La Grande River.

Results with the James Bay Model

As the submodels described above were being completed, it became obvious that the overall model would be able to accommodate a bewildering variety of policy options, and that sensitivity analyses on every component of possible research interest would not be feasible. Therefore, we decided to recast the workshop participants into policy analysis groups, each representing a major interest group in the James Bay controversy. Each group was then asked to do three things: 1) develop a short list of simulation variables that best indicate those aspects of system condition that are of concern to the interest group; 2) formulate one or two overall management scenarios, each expressed as a combination of input interventions, that the group felt intuitively

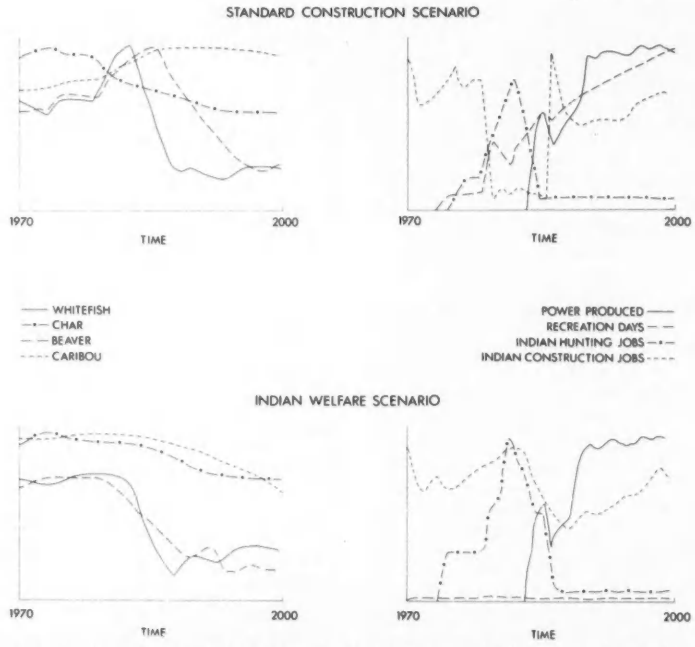

FIG. 6. Sample predictions from the James Bay model for three alternative management scenarios. All predicted values are on relative scale as in Fig. 3.

would represent best management; and 3) develop a set of a priori intuitive predictions about the effect of each intervention on each output indicator variable. After some discussion, we decided to have three of these groups: resource development, environment, and Indian welfare.

Results from the scenario runs proposed by these groups are shown in Fig. 6. In all three cases it was assumed that the overall hydroelectric development would occur, but with different sorts of restrictions on construction activities, management of flows and levels after construction, and access to the area for recreation. A qualitative comparison of predictions made by the model as opposed to intuitive predictions made by the policy groups is presented in Table 3. It is interesting to note that the basic impacts (positive or negative) predicted by the model were exactly opposite from what had been expected for over 70% of the intervention-indicator combinations. In every case, a simple explanation for the difference was clear after brief examination of the model structure, and the participants generally agreed that there had been obvious flaws in their intuitive reasoning.

The model made three major predictions that were counter to any expectations expressed either by the workshop group or in published impact statements related to the James Bay area. First, by providing an overall bookkeeping assessment of the land and water areas involved in hydroelectric development, the model pointed out that the direct impacts of dam construction are not likely to be all that significant; only a small percentage of the land will actually be inundated. Second, by far the largest impact on fish and wildlife resources is likely to come from the increase in recreational demand; in retrospect it is obvious that even small recreational fisheries can seriously deplete northern lakes and streams that can support only a few fish per acre, turning over only once every several years. Finally, it is not simply the case that more intensive hydroelectric development in the area would result in worse environmental problems. We tested the model with the standard La Grande Complex construction plan, then compared this to an even more elaborate dam and diversion plan that has been contemplated (the Complex du Nord). The hydrology submodel predicts that the La Grande Complex would not result in much regulation of water flows and levels, so reservoirs would be

TABLE 3. Qualitative summary of management interventions, and their simulated impacts according to the James Bay model as opposed to intuitive predictions of workshop participants. Sign before each slash is intuitive expectation of impact (+ for beneficial); sign after slash is simulated direction.

	Area of impact															
	Resources				Environment								Indians			
Policy intervention relative to published plans	Power generated	Indian harvests	Nonconsumer recreation	Employment	Quality	Char	Trout	Pike	Whitefish	Caribou	Beaver	Geese	Harvest jobs	Welfare load	Salary jobs	Abundance of game
								Power								
Slower dam construction	-/-	+/-	+/+	+/0	+/-	+/-	+/-	+/-	+/-	0/0	+/-	-/+	+/-	-/0	+/+	+/-
No water diversion	-/-	+/-	+/-	0/-	-/+	+/-	0/0	+/-	+/+	0/0	+/-	+/-	+/-	-/+	-/-	+/-
Control minimum water flows	-/-	+/0	+/+	0/0	+/+	+/+	+/0	+/0	+/+	0/0	+/0	+/-	+/0	-/0	-/0	+/0
								Quality								
Clear trees in reservoir pool	0/0	+/0	+/+	+/+	+/+	+/0	+/-	+/-	0/0	0/0	0/0	+/0	0/-	0/0	0/+	+/0
Control slit input	0/0	+/+	+/+	+/0	+/+	+/+	+/0	+/0	+/+	0/0	+/0	+/0	+/+	-/-	+/-	+/0
								Demand								
Indian job interest	0/0	+/-	0/0	+/+	0/0	0/+	0/+	0/+	0 +	0/+	0/+	0/+	-/-	-/-	+/+	0/+
Jobs allocated to Indians	0/0	-/-	0/+	0/0	0/+	0/+	0/+	0/+	+/+	0/+	+/+	+/+	-/-	-/-	+/+	+/+
Access controlled to reduce recreation	0/0	+/+	-/-	-/-	+/+	+/+	+/+	+/+	+/+	+/-	+/0	+/+	+/0	-/+	+/-	+/+

surrounded much of the time by large mudflat areas that would not be attractive for recreation (geese might prosper by these areas). On the other hand, the complex diversion scheme in the Complex Du Nord should result in much stabilized flows and levels, making river banks and reservoirs more attractive for recreation (but some waterfowl habitat would be lost).

Considering these predictions, it is not surprising that the workshop suggested several possible changes in impact assessment studies. In particular, it appears that much more emphasis should be placed on monitoring of lands and waters that are not directly involved in the development but that will be made accessible for recreational use. Also, the impacts of the construction workers should be carefully monitored. Obviously the whole question of Indian values and resource utilization needs to be looked at much more carefully.

Throughout the workshop, participants were asked to compare information requirements of the model to the data gathering plans that have already been formulated for the La Grande area. In general, we concluded that the plans as currently formulated for intensive surveys and environmental monitoring would contribute very little to future management models, even though data gathering for eventual systems analysis is considered by Environment Canada to be a central goal in the James Bay area. It is hard to imagine how effective management decisions about the James Bay area can be made without answers to some of the questions that arose during the development of the model described above, and it is clear that those questions will not be answered by the impact studies now planned. We have as yet no way to assess whether or not this point will be remembered by the workshop participants, some of whom will be making decisions about allocation of research effort in the next few years. A workshop wrap-up session was held to sound out participants about what they had learned, but the results were inconclusive. Many participants were enthused, but others felt that their own study plans had been made to seem foolish or irrelevant. In the defense of empires, rational thinking is often put aside.

Discussion

Obviously most of the parameter estimates used in the two models were pure guesses; in may cases better estimates simply do not exist, especially those related to recreational demand. Simulation models in resource management are often open to this criticism, and typically the conclusion is drawn that modelling is premature. The James Bay exercise points out very nicely the fallacy of this conclusion; given current direction of research and monitoring effort, the appropriate data would never be collected. We tend to forget that all data collection is guided by some model of nature; workshops and other exercises only try to bring this model out into the open so that its basic assumptions can be examined objectively.

A central problem that we have not touched in discussing either of the models above is validation. Both models deal with long-range predictions that we cannot hope to test with a few years of data monitoring or with any carefully planned experiment. It might be possible to validate (or reject and replace) some of the submodels, but the major prediction errors will probably be due to factors and system components that have not been considered at all. For example, a whole new set of problems in small watershed management could arise if economic factors permit a major shift in forest practice from rotation logging to intensive tree farming. The point is that resource model predictions are usually conditional on the assumption that social and economic factors which determine resource demand will not change in the future; since this assumption is not reasonable, it is absurd to demand that any resource model have absolute predictive power.

Why develop resource models at all, if validation is impossible and if any long range predictions are almost sure to go wrong? Most participants in our modelling workshops have felt that the exercises were worthwhile; have they been deluding themselves? The best answer to these questions appears to be that resource models must be judged relative to one another and against intuitive decision-making paradigms. We must somehow make decisions about resource problems, so some model is always going to be used; we need only ask whether it is worthwhile to make this model explicit. Validation questions should not be couched in the form, "Is this model correct?" Rather, we should ask, "Is this model more likely to give correct answers than any alternative which we can now envision and implement?"

During the Silt Creek and James Bay workshops, we faced some serious technical problems for which we were not able to provide adequate answers and which forced us in many cases to be more simpleminded than was necessary considering available data. Most of these problems are related to the limited speed and capacity of

electronic computers in handling discrete representation of phenomena that occur more or less continuously in time and space. We were not able, for example, to provide a really clear picture of impacts on the small lakes and streams that may be very important for recreation in the James Bay area; all of these waters within each large land unit were considered to be equally accessible and productive. In the Silt Creek model, we might have obtained much better estimates of pollutant transport rates by considering water flow variations associated with each storm event, since the short peak flow periods are critical for material transport; obviously this would require much more computation time. There do not as yet exist any objective criteria for deciding how much spatial and temporal resolution is necessary in particular models, since simplification can lead to a variety of different kinds of errors. The only suggestion that can now be made is that the model builder should not rely on a single representation of any system; several alternative schemes should be tried, and the results compared for error patterns.

The Silt Creek and James Bay exercises strongly suggest that the major information need for watershed management modelling is not associated with any of the traditional resource disciplines. We can muddle along with existing understanding about hydrology, forestry, fisheries, and wildlife; where the models really fail is in representation of demands for resource use. Too often fisheries and wildlife investigators assume either that the animals can take care of themselves, provided that habitat conditions are maintained, or that demand will automatically adjust to whatever conditions of abundance prevail. Likewise, little is known about nonconsumptive demand for wildland resources and about demands for recreational cabins and lots.

It is easy to criticize many simulation models in ecology on the basis that they contain only figments of the imagination of the model builder, who often has only a superficial understanding of the system that he is trying to describe. We believe that the workshop approach, by making possible a more intimate feedback between model and subject matter expert, has helped to alleviate this problem in the models described above. The assumptions and functional relationships in each seem to capture (and in some cases go beyond) the basic state of understanding in the disciplines concerned, though we could certainly go back and considerably elaborate each submodel. However, it hardly seems worthwhile to spend time on more elaborate models, considering the major information gaps that even the simple models described above have helped to identify.

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Assessment of the Impact of Hydro-dams[1]

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EFFORD, I. E. 1975. Assessment of the impact of hydro-dams. J. Fish. Res. Board Can. 32: 196–209.

At present, assessments of the impact of a dam are becoming part of the design process but they are still not completed early enough to affect the overall decision to construct a particular dam at a particular site. Thus, their real value is lost because attempts to correct social and environmental problems are made after rather than before the problem has arisen.

Impact statements at the moment assess only alternatives to the design of a dam. They ought to include analyses of alternative uses of the valley, the long-term value of delaying the decision, the relative merits of generating power by other means, and finally the merits of reducing energy demands by rationing or raising prices. The assessment of impact should be considered a positive contribution to helping the decision-maker rather than an annoying complication preventing him from getting on with his job.

In today's increasingly complex world we must proceed more cautiously because the synergistic interactions, resulting from major undertakings like dams, pipelines etc., are many and frequently not obvious. Public access to impact assessments is an essential aspect of the democratic process and will help to anticipate some of these problems.

EFFORD, I. E. 1975. Assessment of the impact of hydro-dams. J. Fish. Res. Board Can. 32: 196–209.

A l'heure actuelle, l'évaluation de l'impact d'un barrage est partie intégrale de l'avant-projet, mais il demeure que les études ne sont pas terminées à temps pour affecter la décision de construire un barrage particulier à un endroit particulier. Ces études perdent donc leur valeur réelle, puisque les efforts en vue de rectifier les problèmes sociaux et environnementaux sont appliqués après plutôt qu'avant l'apparition des problèmes.

Les études d'impact se limitent pour le moment à une évaluation des diverses alternatives dans la préparation de l'avant-projet. Elles devraient inclure une analyse des usages alternatifs qu'on pourrait faire de la vallée, des avantages à long terme à différer une décision, des mérites relatifs de sources alternatives de pouvoir et, finalement, des avantages à réduire la demande en énergie par rationnement ou par augmentation des prix. Une étude d'impact devrait être considérée comme une contribution positive pour aider celui qui prendra une décision, plutôt qu'une complication ennuyeuse qui l'empêchera d'aller de l'avant avec le projet.

Dans un monde qui devient chaque jour plus complexe, il nous faut exercer une plus grande prudence, car les interactions synergiques qui entrent en jeu dans des projets de l'envergure de barrages, pipelines, etc. ne sont pas toujours évidentes. L'accessibilité des études d'impact au public est un aspect essentiel du processus démocratique qui permettra d'aller au-devant de certains de ces problèmes.

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THERE is a growing acknowledgment in Canada that environmental impact assessments for new hydro-dams should be prepared, but in many cases they are still initiated after the decision to build the dam has been made. This timing arises because impact studies are considered as ancillary to a fully-designed project rather than as an integral part of the engineering and economic studies, where the analysis can result in changes to modify and improve the design at an early stage.

By performing environmental impact assessments only after the decision to build a dam, we lose the real value of such studies and their function is relegated to anticipating problems requiring patch-work solutions and assuaging the concern of an aroused public. Political decisions to build dams are still dominated by an outdated growth ethic. Some new dams should be built, but only after we are certain that the energy is needed and that the external costs associated with

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all aspects of power generation — from the dam itself to the home or factory — have been included in the price of the electricity.

The Impact Statement

The idea of an impact statement is that it should be a critical review of the proposed project which tries to anticipate the problems that might arise and in some cases alleviate these problems by proposing design changes. Ideally, it should contain three separate sections. The first will contain a description of the actual project, such as a dam, and an analysis of the social and environmental effects that will result from its construction. This analysis should not be restricted to a short time span, but should try to anticipate the effects over at least the first 50 yr. It should also consider the implications of the project for further developments. For example, if we build one dam on a river it regulates the flow in such a way that future dams on the river are much more likely. The analysis should anticipate the construction of these other dams and discuss their overall effect.

The second section, one that is usually ignored or considered only superficially, is a review of the alternative uses of the valley should it remain unflooded. Could it more profitably be used for forestry, recreation, mining, or some combination of all three? What is the availability of this type of valley in that region? Just because a project is proposed does not mean it should go ahead if there are better uses of the resource. Unfortunately, up to now most proposals for large dams have been approved without serious considerations of such questions.

The third section is one that has not yet been implemented in Canada. This is an analysis of alternatives to the project itself, such as substitution of nuclear power plants or damping the demand for power, thus eliminating the need for the dam at this time.

The role of the impact statement is such that it must be prepared early in the planning stage so that the data can be used both in the planning of the project and in the decision whether or not to proceed. The arguments for and against the project must be balanced, not heavily weighted on the side of the project as is so often the case.

One of the central problems preventing real environmental impact statements being prepared is the lack of a clear direction as to who should judge any study. Obviously, the developer should fund the analysis prepared within the company or by a consulting company. Some organization independent of the project should judge the study and if special analysis is required in the judgement it should be funded by the developer. Because all aspects of the impact will be realized only after the widest discussion, the report should be made available to the public well before any hearings take place; thus a large lead time is one of the prerequisites of any new development. The benefits are suggestions from the public which may considerably improve the design.

Some Problems

Our ability to measure the impact of hydrodams on biological systems is not well developed. Thorough ecological studies usually require very different time scales from the construction schedules, and even if given the time a biologist may not be in a position to do more than a superficial analysis. The reason for this is that the reservoir created by a dam will obviously change the plants and animals in the area to be flooded. If there are some populations of very rare species in the area they can be documented easily and the effect on the species estimated. Thus if the project is going to eliminate the condor or the whooping crane, clearly it should not proceed. Such a clear cut situation is very rare. Usually, the area to be flooded will contain only common animals and plants and the effect of the reservoir will only be a change from a terrestrial to aquatic biota. At this point a value judgement must be made and biologists have no criteria on which to base these judgements. If only a large forested valley is flooded, the trees, wildlife, soil, animals, etc. will die and be replaced by at least as many aquatic animals and plants. Is this good or bad? In either case there is very little benefit gained from a detailed count of the number of animals and plants to be lost. This benefits no one except the environmental consulting company.

Changes are judged to be bad only if there is a clear-cut loss to man himself. This loss may include loss in commercial timber or recreational use of the valley, or it might include the less tangible loss of an "alternative future," i.e. the benefit of delaying the decision for a number of years, at which time, because of changing values within society, our decision whether or not to build the dam might well be different. The benefits of a reservoir might well replace the commercial or recreational losses but frequently this has not been the case because of the single purpose use of the reservoir. The impact statement must

compare the benefits and costs associated with single purpose use with those incurred by clearing the trees and regulating the water level so that recreational use is maximized in the summer months.

These problems are compounded if there is a scarcity of the resource we are planning to alter. If there are a great many valleys of a similar type remaining in an area — for example, steep-sided valleys in Northern British Columbia — then the replacement of land by water is far less significant than when there are only one or two such valleys left, as in northern Manitoba. What is the scarcity value for valleys, or more importantly, what will that value be in 50 yr?

Canadian history gives us too many examples of what were once regarded as so-called useless wilderness areas, such as the prairies and the Banff region, which today are recognized as priceless. The people constructing the dam on Stave Lake in 1911, only 50 miles from Vancouver, assumed it had little recreational value and left the trees standing as a reminder of past attitudes. Little did they anticipate the enormous recreational pressure which would develop in the area within a few years, a pressure which now results in plans to clear dead stumps from the lake. A good environmental impact statement should anticipate this type of problem and assign a value to the future potential of an area in a natural or developed state.

An effective impact statement should be based on three principles: first, what is the relative weight of the natural system to be altered in terms of the total supply of similar systems in the region; second, what is the direct impact on the environment of the proposed alterations (more conventionally thought of as an impact statement); and third, what is the potential future demand within the region for areas of the type in question. An impact statement should be as much an assessment of supply and demand as it is of direct physical change. Only when a supply position is established can many of the intangible value judgements be made intelligently.

A Case Study — The Skagit Valley

The Skagit Valley in British Columbia can be used to illustrate some of the problems associated with estimating the impact of a reservoir. The valley lies about 100 miles east of Vancouver on the Canadian–U.S. border. Seattle City Light Co. built Ross Dam in the U.S. which floods the valley to the border. They now wish to raise the dam and increase the area of Ross Lake; to achieve this, 6000 acres in Canada must be flooded. Opposition by many Canadians and Americans since 1969 has delayed the proposed flooding and more recently opposition has been expressed by both the Federal and Provincial governments. Despite clear Canadian opposition to the flooding, Seattle City Light Co. feels it has the legal right to go ahead with the project.

An environmental impact study initiated by Seattle City Light cannot be termed complete, as it failed to examine the value of the valley in its present state, as well as the alternative uses which could be made of the valley. They funded a great deal of data gathering in the valley aimed at measuring changes that would take place after flooding, and at anticipating problems that might arise. Also, this study was used to point out the "benefits" Canadians would receive from the flooding as well as to design cosmetic changes that would make the development more acceptable. Unfortunately, the final results cannot be viewed as a true environmental impact statement as it failed to concern itself with the alternative benefits to Canadians of not flooding the valley. These important missing aspects, necessary to complete the full story, were left to a group of eight students, funded by an Opportunities for Youth Project, who did an 8-wk study designed to assess the valley's potential for recreation, forestry, etc. in an unflooded state. They were able to show that, unlike many of the other valleys in the Vancouver region, this particular valley would be of far greater value unflooded than flooded. In the flooded state we would benefit only by having a slightly lengthened Ross Lake which is already used by Canadians for fishing. What we would lose is a valley which is rather exceptional for a number of reasons. It is large and flat-bottomed, an unusual feature in the coastal mountains, and has an exceptionally warm, dry, and sunny climate for a valley that near the coast. The climate has resulted in the mixing right in the valley of the wet coastal vegetation with dry interior vegetation. Thus the area has an extensive variety of both. Furthermore, it has an exceptionally attractive and accessible river which is noted for the quality of its fly fishing, canoeing, and general recreational potential. The Skagit Valley would in fact make an ideal site for a Provincial Park (in October 1973 the B.C. Government announced creation of the 92,000-acre Skagit Valley Recreation area which includes the area proposed for flooding); however, its key value in this regard is that it is the

only valley within a day's return drive of Vancouver which is both suitable and available for this purpose. The OFY study (Adams et al. 1971) compared 13 other valleys in the region that might be used in this way from the point of climate, physiography, fish and wildlife, and access, and no other valleys had the potential and were publicly owned.

Thus, the environmental impact of raising the Ross Dam cannot be measured by a detailed analysis of the biological systems within the valley alone, but can be examined only by looking at the overall region together with the rapid increase in the demand for recreational land by the four million people living in the northwest state of Washington and the Fraser Valley of British Columbia. A projection of this demand indicates that it will swamp the facilities — including those that might be provided in the Skagit Valley — in the next few years. Any impact study that fails to include an analysis of what could be achieved with the resource if the project does not go through, is sadly lacking in both objectivity and wisdom.

We cannot leave the Skagit example without pointing to another gap in the analyses prepared by Seattle City Light. They have failed religiously to examine the possibilities of reducing electrical consumption in Seattle, by using electricity more efficiently, or by raising the price to damp down demands. They advertise that they use the most power per capita in the U.S. as well as having the cheapest rates. Yet one would expect that any reasonable impact analysis would consider the alternative of doing without the new power.

Another Case Study — The Churchill–Nelson

A second major example of concurrent rather than precedent impact assessment exists in northern Manitoba, where, unlike the Skagit Valley, impoundments are now under construction. As early as 1878, surveys of the Churchill and Nelson rivers suggested that a vast northern hydroelectric potential existed, and that it should be utilized some day. In the ensuing eight decades, hydroelectric power was developed on all major southern rivers in Manitoba, primarily as run-of-the-river plants with some upstream storage: that is, the Winnipeg River, Lake of the Woods, and now Lake Winnipeg. In most cases, operating levels for impoundment were either set within the natural range, or extensive bank protection and clearing programs were undertaken.

In the 1960s, the first Nelson River plant was commissioned to service the International Nickel Company. As southern Manitoba power demands continued to grow, more plants were planned for the Nelson, but on a scale that could support major expenditures for storage and diversion. At this stage a decision was made, on the basis of economic efficiency, to depart from developing each river system individually, and to depart widely from natural water levels with minimum clearing at points of access only. The plan, now under construction, will divert 80% of the Churchill River flow southward across the drainage divide separating the Churchill and Nelson rivers at Southern Indian Lake. The flow of approximately 25,000 cfs will enter the lower Nelson River 200 miles downstream via two small river systems called the Rat and Burntwood. Designs for lower Nelson plants were subsequently enlarged by 30–40% in capacity to deal with the combined river systems.

When this decision was announced as governmental policy in 1967, opposition to this particular form of hydroelectric development was voiced at public hearings under the Manitoba Water Power Act. It became apparent that although the hydro (engineering) aspects of planning were competent and complete, there had been no studies or planning for the physical and social disruption of such a major rearrangement of hydrologic regimes. The hearings were terminated by an election in 1969 in which the government was defeated.

The new government sought the advice of hydro-engineering consultants on possible rearrangements for the diversion scheme but again chose to pursue (a) a diversion rather than individual development of the river systems, and (b) a solution in which some remedial modifications were made but which was justified primarily by the power benefits. The decision to pursue the diversion configuration now under construction was not referred to the Manitoba Water Commission, which would have held public hearings. Instead, licensing was simply granted by Order-in-Council.

The Churchill and Nelson River systems display unique characteristics in a generally harsh northern environment in much the same way as the Skagit Valley is distinct to southern British Columbia. The two river systems import water from the south and west in a hydrologic regime that has established large stable valleys and extensive stable lake shorelines. Impounding of the Churchill River at Southern Indian Lake and

downstream to facilitate passage of the water over the drainage divide will flood approximately 300 square miles of forested land in a predominantly permafrost area. A minimal clearing program in the immediate areas of installation and along the diversion channel deals with only a small portion of the flooded area. Erosion of shorelines and river valleys will be rapid in the frozen soil areas and on the largely abandoned 200 miles of the lower Churchill River. The total area and volumes of materials to be degraded, eroded, and redeposited indicate that the region will be unstable for a considerable length of time. Experience in other small northern reservoirs suggests that the period of major instability will extend throughout contemporary planning horizons of 50–100 yr, at a minimum. In effect, most of the multiple use potential aspects of the Nelson and Churchill valleys will be greatly decreased or eliminated for the near future.

Concurrently with construction of the project, a joint Federal/Provincial Impact Study was undertaken to determine what the effects of the diversion will be. The study will ultimately lead to proposals for mitigation. However, the study is limited to accepting the basic hydroelectric configuration, flood levels, discharges, etc., and cannot for example consider nonflooding or nondiversion alternatives. In 1975 the Impact Study will provide data on the effects on the hydrologic regime, fish and fur production, and local communities, but only after the project is in operation. The quality of the concurrent study has also suffered from the short time schedule of construction. If in a study of this nature, for example, a trial impoundment in a permafrost area had begun in 1964 when the joint Federal/Provincial Study of Nelson River power potential began, 8 yr of data on erosion, turbidity, and reestablishment of shorelines would have been available at the time of the final decision to proceed with the project.

A general reaction to the Churchill River diversion is epitomized by P. D. McTaggart-Cowan and others (E. D. Gillespie et al. 1972) in a report to Manitoba Hydro in which the authors stated: "We sincerely hope that this will be the last time in the history of Manitoba that major engineering endeavours are undertaken without a proper environmental impact study having been completed so that it is one of the essential inputs to the political decision."

Paradoxically, it will be the last time as there are no other large rivers suitable for diversion in northern Manitoba. However, the rationale expressed is readily transferable to a Mackenzie Valley pipeline, the James Bay development, or to any major hydroelectric development in Canada's future.

Conclusions

As we move toward recognizing the true significance of real environmental impact in Canada, we must consider the benefits to be gained, rather than the disadvantages. The politicians fear the loss of their right to make off-the-cuff decisions about projects which, like the James Bay development, can have a major impact on our national or provincial economies. Environmental impact statements must be complete before the project is approved, and be part of the information that is used by politicians when comparing alternative solutions to a problem. The statement should include not only the obvious analysis of the project itself, but also an analysis of the alternative use of the resource (e.g. the valley), and the increased value gained by leaving the choice of its use open until a future date — that is, the value of maximizing our future alternatives. It should also include an analysis of alternative power sources and an honest demonstration of the need for more energy.

One of our major problems is the lack of integrated planning on energy in Canada. We are an energy rich country, and unlike many countries, we do have a choice of how to produce our power. Yet frequently, decisions on electric projects appear to be based on an analysis of part of our energy base rather than the whole. Finally, the statement should include an analysis of the costs and benefits of reducing, rather than satisfying, the electric demand.

Environmental impact statements are not a device established to reduce the power of politicians, but are designed to improve the quality of information for decision making, and thereby improve the quality of our government. They should be initiated simultaneously with the economic and engineering studies that precede the choice of dam sites, and their findings should carry equal weight in the decision-making process. In an increasingly complex world, decision making itself becomes more difficult, and thus the politician or senior government official needs more help. Analyses of the impact of large dams should be public documents which help the politician, and at the same time form the basis of discussions which precede the political decision.

I would like to conclude with a quotation from

the recent Green Paper on Energy Policy (Ministry of Energy, Mines, and Resources, 1973, p. 281). "Few if any other countries have as great an opportunity to develop their country in harmony with Nature to achieve long-term prosperity. Perhaps few also still have as great a chance to make colossal blunders in managing their environment." If we would spend more effort on considering the social and environmental impact of our engineering plans, like hydro-dams, we might reduce the number of colossal blunders that Canada will suffer in future years. This can come about when we combine long lead time for projects, detailed environmental impact statements which include consideration of alternative uses and alternative solutions, and broad public access to information and participation. Is this too much to ask in our present free democracy?

Acknowledgments

This paper is an expansion of ideas presented by I.E.E. and R. W. Newbury to the Engineering Institute of Canada on October 1, 1973 in Montreal.

ADAMS ET AL. 1971. The future of the Skagit Valley. (Submitted to the International Joint Commission, July 31, 1971.)

GILLESPIE, E. D., F. F. SLANEY, AND P. D. MCTAGGART-COWAN. 1972. Report to the chairman of Manitoba Hydro on the clearing program for Southern Indian Lake and the diversion channel from South Bay to Notigi. 1–24.

Appendix

Reservoirs of Major Canadian Hydroelectric Projects

By 1972, there were some 365 hydroelectric projects in Canada, affecting over 200 rivers and streams. Most of these are relatively insignificant sources of energy, but 80 large dams, affecting 53 major rivers, have capacities of more than 100 MW.

All projects exceeding 100-MW capacity which were operational or under construction in 1974 are listed in Table A I. A number of other large developments planned in Labrador, Québec, Manitoba, and British Columbia are not included.

Explanatory notes

Utility or company — Current owner or operator of the project.

Project first power — Usual name of project. (Date of first power production.)

Capacity — Present or ultimate installed electric generating capacity (Megawatts).

Reservoir area total (flooded) — Usual name of reservoir (if named). First figure indicates total surface area of reservoir in square miles. Parentheses denote area of land flooded (= total minus original lake area).

Annual drawdown average (max) — First figure indicates average annual vertical fluctuation of reservoir in feet. Parentheses denote maximum possible drawdown.

Comments — Regional location of project. Comments on clearing incorporate best available information.

Symbols

NA (NA) — Information not available.

* — Ultimate electric capacity at completion of project.

† — Installed capacity $\geqslant$ 100 MW.

Information on project names, date of first power, capacity, rivers affected, and location was obtained from the following sources:

Statistics Canada, *Electric Power Statistics 1972, Volume III*. Catalogue 57-206 Annual. Information Canada. Ottawa 1973.

Canadian National Committee of the International Commission on Large Dams. *1970 Register of Dams in Canada*. H. K. Pratt [ed.] Montreal. 1970.

Energy Development Sector, Department of Energy, Mines and Resources. Electric Power in Canada 1971. Information Canada, Ottawa, 1972.

Information on reservoir areas, lands flooded, drawdowns, and extent of reservoir clearing was provided through the kind cooperation of the following: Newfoundland and Labrador Power Commission; The Bowater Power Company Limited; Churchill Falls (Labrador) Corporation Limited; The New Brunswick Electric Power Commission; Mr D. Folster, Fredericton, N.B.; Aluminum Company of Canada Limited; Commission Hydroélectrique de Québec; Hydro Electric Power Commission of Ontario; Manitoba Hydro; Saskatchewan Power Corporation; Saskatchewan Water Management Service; Calgary Power Limited; Cominco Limited (British Columbia); British Columbia Hydro and Power Authority; British Columbia Water Rights Branch.

TABLE A 1. Reservoirs of major Canadian hydroelectric projects.†

Province	Utility or company	Project (first power)	Capacity (*MW*)	River(s) dammed or diverted	Reservoir area (*sq. miles*) total (flooded)	Annual drawdown (*ft*) average (max)	Comments
Nfld.	Newfoundland and Lab. Power Comm.	Bay d'espoir (1967)	459	Salmon Grey Northwest White Bear Victoria	Long Pond: 72 (50) Meelpaeg: 122 (43) Burnt: 12 (2) Granite: 30 (20) Victoria: 54 (30)	2 (5) 3.5 (5.5) 2 (3) 7 (9) 5.5 (7)	South–central Newfoundland. Total area flooded approx. 145 sq. miles. No clearing of vegetation before flooding.
"	Bowater Power Co.	Deer Lake (1925)	125	Junction Brook	Grand Lake: 190 (NA)	8 (13)	Western Nfld. Natural lake raised 30 ft for additional storage, flooding only narrow margin along steep shores. No clearing before flooding. Power plant is at Deer Lake.
Nfld. (Lab.)	Churchill Falls (Labrador) Corp.	Churchill Falls (1971)	5225*	Churchill Naskaupi Kanairiktok	Smallwood: 2200 (1100)	12 (28.5)	Western Labrador. 5 sq. miles cleared before flooding, 11 sq. miles cleared after flooding.
"	Twin Falls Power Corp.	Twin Falls (1962)	234	Unknown River	Ossokmanuan: 367 (92)	12 (13.5)	Western Labrador. Negligible clearing before flooding, none after.
N.B.	New Brunswick Electric Power Comm.	Mactaquac (1968)	600*	Saint John	32.3 (23.4)	5 (20)	Southern N.B. Completely cleared before flooding.
"	"	Beechwood (1957)	113	Saint John	18.4 (NA)	5 (20)	West–central N.B. Completely cleared before flooding.
Qué.	Hydro-Quebec James Bay Development Corporation	LG 2	4410 (1980)	La Grande dammed Great Whale Eastmain diverted	forebay 1550 (NA) Bienville 420 (NA) Lake Sakami 1120 (NA) Lake Opiheka forebay	NA (30)	West–central Québec. The reservoirs are shallow. Most of their beds will be exposed at times of low storage. A considerable amount of timber will stand above water level. No information available on clearing, presumed unclear. Recent labor strife and economic difficulties associated with the project will delay completion of some of the dams. LG 2 has been delayed at least a year, work on LG 1 has been postponed indefinitely, and plans for LG 3 will have to be modified considerably if the dam is to be built.
"	"	LG 3	1500 (1982)	La Grande	forebay 720 (NA)	NA (30)	
"	"	LG 4	1500 (1983)	La Grande dammed Caniapiscau diverted	Delorme 500 (NA) Caniapiscau 820 (NA) Puisseaux 125 (NA) forebay 287 (NA)	NA (NA)	The James Bay Energy Corporation has announced that it is expanding the project to include the NBR complex (comprising the Waltaway, Broadback, and Rupert rivers), thereby increasing the total project capacity by 40% to 11,100 MW at an estimated cost of $12 billion.
"	"	LG 1	320 (1984)	La Grande	forebay 30 (NA)	NA (5)	
Qué.	Aluminum Co. of Canada	Passes Dangereuses (1942)	743	Péribonca	NA (NA)	50–60	Lac St-Jean region. Large reservoir. No information available on extent of clearing.
"	"	Shipshaw (1942)	717	Saguenay	NA (NA)	NA (NA)	Saguenay region. No information available on extent of clearing.

TABLE A 1—*continued*

Province	Utility or company	Project (first power)	Capacity (*MW*)	River(s) dammed or diverted	Reservoir area (*sq. miles*) total (flooded)	Annual drawdown (*ft*) average (max)	Comments
Qué.	Aluminum Co. of Canada	Chute à la Savanne (1952)	187	Péribonca	NA (NA)	0 (NA)	Lac St-Jean region. No information available on extent of clearing.
"	"	Chute du Diable (1952)	187	Péribonca	NA (NA)	15 (NA)	Lac St-Jean region. No information available on extent of clearing.
"	"	Chute à Caron (1928)	180	Saguenay	NA (NA)	NA (NA)	Saguenay region. No information available on extent of clearing.
"	Manicouagan Power Co.	McCormick Dam (1951)	304	Manicouagan	NA (5.6)	0 (NA)	North shore St. Lawrence (Baie Comeau). Presumed uncleared before flooding. Flow regulated by upstream projects.
"	Saguenay Power Co.	Isle Maligne (1925)	336	Saguenay	Lac St-Jean NA (0)	NA (NA)	Saguenay region. Regulation conforms to former regime of natural lake. No land flooded.
"	Hydro-Québec	Beauharnois (1932	1574	St. Lawrence	NA (NA)	4 (NA)	Southwestern Québec.
"	"	Manic 5 (Barrage Daniel Johnson) (1970)	1292	Manicouagan	753 (608)	35 (65)	North shore St. Lawrence (Baie Comeau). Approx. 15% of merchantable timber harvested, otherwise no clearing before flooding.
"	"	Manic 3 (1975)	1185*	Manicouagan	NA (NA)	NA (NA)	North shore St. Lawrence. Last project of Manicouagan development.
"	"	Manic 2 (1965)	1015	Manicouagan	43 (NA)	5 (5)	North shore St. Lawrence. No information available on clearing of Manic 2 basins — presumed uncleared.
"	"			Toulnustouc	Lac Ste-Anne: 97 (57)	78 (100)	Upstream storage by dam on Toulnustouc River 1959. Some harvesting of merchantable timber and felling of trees to facilitate future log transport.
"	"	Bersimis 1 (1956)	912	Bersimis (Betsiamites)	Lac Cassé: 306 (146)	25 (33)	North shore St. Lawrence (Labrieville). Expansion of previous lakes Cassé and Pipmuacan to dams preventing drainage into Saguenay watershed to west. Substantial portion of merchantable timber harvested and partial felling and clearing of timber before flooding.
"	"						
"	"	Outardes 3 (1969)	756	Outardes	Lac Tirebouchon: NA (NA)	5 (5)	North shore St. Lawrence (Baie Comeau). Reservoir enlarges natural lake. Water diverted to underground powerhouse, leaving approx. 15 miles of former river channel dry except for spillage. No information on clearing — presumed minimal.
"	"	Bersimis 2	655	Bersimis (Betsiamites)	NA (NA)	8 (10)	North shore St. Lawrence. No information available on clearing — presumed minimal. Large area flooded but no figures available.

TABLE A 1—*continued*

Province	Utility or company	Project (first power)	Capacity (*MW*)	River(s) dammed or diverted	Reservoir area (*sq. miles*) total (flooded)	Annual drawdown (*ft*) average (max)	Comments
Qué.	Hydro-Québec	Carillon (1962)	655	Ottawa	NA (NA)	5 (5)	Southwestern Québec. Primarily run-of-river plant, so relatively small area flooded. Presumed cleared. Daily fluctuations in reservoir level during winter.
"	"	Outardes 4 (1969)	632	Outardes	252 (232)	25 (65)	North shore St. Lawrence. Approx. 20% of merchantable timber cut, otherwise uncleared.
"	"	Shawinigan 2 and 3 (1911, 1949)	313	St-Maurice	NA (NA)	3.5 (3.75)	South–central Québec (Mauricie). No information available on clearing.
"	"	La Trenche (1950)	286	St-Maurice	NA (NA)	3 (11.4)	South–central Québec (Mauricie). No information available on clearing.
"	"	Beaumont (1958)	243	St-Maurice	1.7 (NA)	3 (3)	South–central Québec (Mauricie). Approx. 0.78 sq. miles cleared before flooding.
"	"	La Tuque (1940)	216	St-Maurice	4.7 (NA)	2 (2.5)	South–central Québec (Mauricie). No information available on clearing.
"	"	Paugan (1928)	202	Gatineau	Associated upstream reservoirs:		Southwestern Québec (Gatineau). Paugan plant has relatively small reservoir. Upstream control reservoirs expanded existing lakes. No information on extent of clearing — presumed minimal.
					Cabonga: 200 (82)	8 (16)	
					Baskatong: 114 (60)	51 (51)	
"	"	Manic 1 (1966)	184	Manicouagan	5 (NA)	4 (4)	North shore St. Lawrence. Operated in conjunction with McCormick Dam, sharing same reservoir. Flow regulated by upstream projects. No information on clearing.
"	"	Rapide Blanc (1934)	184	St-Maurice	Réservoir Blanc: 32 (NA)	30 (30)	South–central Québec (Mauricie). First of seven projects on Rivière St-Maurice. Approx. 16 sq. miles cleared before flooding.
					Upstream control reservoirs:		Upstream regulation by Gouin (1918) and Manouane reservoirs (1908, 1915). No information on clearing — presumed uncleared. Headwaters of Mégiscane and Susie rivers diverted into Gouin Reservoir in 1954. All St-Maurice projects used for transport of logs.
					Gouin: 580 (371)	15 (37)	
				Manouane	Kempt: 64 (NA)	8 (8)	
					Manouane: 20 (NA)	13 (13)	
					Châteauvert: 14 (NA)	32 (32)	
				Mondonac	Mondonac: NA (NA)	NA (NA)	
"	"	Les Cédres (1914)	162	St. Lawrence	NA (NA)	3 (NA)	Southwestern Québec. Run-of-river plant flooding relatively small area.
"	"	Grand'Mère (1915)	148	St-Maurice	8 (NA)	3 (6.2)	South–central Québec (Mauricie). No information available on clearing.
					Upstream control reservoirs:		Mattawin (1930) and Ciconcine reservoirs provide upstream storage. No information on clearing — presumed uncleared.
				Rivière-aux-Rats	Ciconcine: 5.25 (NA)	13 (13)	
				Mattawin	Mattawin: 50 (>45)	57 (57)	

TABLE A 1—*continued*

Province	Utility or company	Project (first power)	Capacity (*MW*)	River(s) dammed or diverted	Reservoir area (*sq. miles*) total (flooded)	Annual drawdown (*ft*) average (max)	Comments
Qué.	Hydro-Québec	Rapide des Îles (1966)	147	Ottawa		7 (NA)	Northwestern Québec (Témiscamingue). Largest of five Upper Ottawa River power plants totalling 398 MW.
					Upstream control reservoirs:		
					Dozois: 123 (76)	30 (30)	Upstream reservoirs used for both flow regulation and forest exploitation. No information available on clearing, presumed uncleared.
					Victoria: 57 (NA)	8 (8)	
					Decelles: 91 (NA)	7 (7)	
					Rapide 2: 8.7 (5.1)	7.5 (NA)	
					Lac des Quinze: 157 (NA)	11 (11)	
"	"	Chelsea (1927)	144	Gatineau	Upstream storage reservoirs Cabonga and Baskatong. See Paugan above.		Southwestern Québec.
"	"	La Gabelle (1924)	124	St-Maurice	NA (NA)	6 (7.5)	South–central Québec (Mauricie). Last of seven power sites on Rivière St-Maurice. No information available on clearing.
Ont.	Ontario Hydro	Sir Adam Beck no. 1 and 2 (1922, 1954)	1638	Niagara	0.15 (0.15)	0 (0)	Southern Ontario (Niagara Falls). Diversion of river to penstocks. Cleared before flooding.
"	"	R. H. Saunders (1958)	912	St Lawrence	Lake St. Lawrence: 53 (35)	6.6 (9.5)	Southeastern Ontario (Glengarry). Area flooded is partly within USA. Cleared before flooding.
"	"	Des Joachims (1950)	360	Ottawa	31.2 (17.6)	7.7 (9.9)	Eastern Ontario (Ottawa Valley). Reservoir margins and drawdown zone cleared. No information available on clearing of lower basin.
"	"	Rayner/Wells (1950)	246	Mississagi	8.6 (7.7)	13.6 (15.9)	Northern Ontario (Algoma District). Margins and drawdown zone cleared, no information available on further clearing.
"	"	Lower Notch (1971)	228	Montreal	4.85 (3.81)	11.6 (13.7)	Northern Ontario (Temiskamingue District). Completely cleared before flooding.
"	"	Abitibi Canyon (1933)	212	Abitibi	4.89 (4.27)	10.1 (12.5)	Northern Ontario (Cochrane District). No information available on extent of clearing — presumed largely uncleared.
"	"	Otto Holden (1952)	205	Ottawa	12.5 (5.3)	10.9 (13.6)	Northern Ontario (Upper Ottawa Valley). Margins and drawdown zone cleared, no information available on further clearing.
					Upstream control reservoirs:		
					Temiscamingue: 122 (NA)	15 (15)	Upstream control reservoirs are regularized natural lakes. No information available on extent of clearing.
					Kipawa: 106 (NA)	8 (8)	
"	"	Sir Adam Beck P. G. S. (1957)	177	Niagara	1.15 (1.15)	25 (25)	Southern Ontario (Niagara Falls). Artificial reservoir cleared before flooding.

TABLE A 1—*continued*

Province	Utility or company	Project (first power)	Capacity (*MW*)	River(s) dammed or diverted	Reservoir area (*sq. miles*) total	(flooded)	Annual drawdown (*ft*) average	(max)	Comments
Ont.	Ontario Hydro	Otter Rapids (1961)	175	Abitibi	3.6	(1.25)	7.5	(7.9)	Northern Ontario (Cochrane District). Completely cleared before flooding.
"	"	Stewartville (1948)	153	Madawaska	1.69	(0.83)	4.6	(6.3)	Eastern Ontario (Renfrew). Margins and drawdown zone cleared, no information on further clearing.
"	"	Barrett Chute (1942)	152	Madawaska	5.13	(2.92)	6.0	(8.0)	Eastern Ontario (Renfrew). Margins and drawdown zone cleared, no information on further clearing.
"	"	Mountain Chute (1967)	140	Madawaska	Centennial Lake: 13.3	(10.6)	13.1	(14.7)	Eastern Ontario (Renfrew). Completely cleared before flooding.
"	"	Aubrey Falls (1969)	130	Mississagi	8.56	(6.74)	8.7	(11.0)	Northern Ontario (Algoma District). Completely cleared before flooding.
"	"	Pine Portage (1950)	129	Nipigon Ogoki	Lake Nipigon 1750	(8.9)	2.9	(3.9)	Northern Ontario (Thunder Bay District) Regulation of natural lake. Cleared before flooding. Ogoki River partially diverted (4000 cfs) into Lake Nipigon to increase flow.
"	"	Harmon (1965)	129	Mattagami	0.97	(0.19)	7.9	(8.8)	Northern Ontario (Cochrane District). Completely cleared before flooding.
"	"	Kipling (1966)	125	Mattagami	0.55	(0.25)	7.9	(8.7)	Northern Ontario (Cochrane District). Completely cleared before flooding.
"	"	Little Long (1963)	122	Mattagami	29.4	(17.9)	9.4	(11.9)	Northern Ontario (Cochrane District). Completely cleared before flooding.
"	"	Chenaux (1950)	122	Ottawa	7.17	(2.86)	5.1	(6.2)	Eastern Ontario (Ottawa Valley). Margins and drawdown zone cleared, no information on further clearing.
"	"	Decew Falls (1943)	115	Welland Canal	Lake Gibson 1.03	(1.00)	10	(10)	Southern Ontario (Niagara Peninsula). No information available on clearing — presumed cleared.
"	"	Ontario Power (1905)	101	Niagara	0.016	(0.016)	4.3	(4.3)	Southern Ontario (Niagara Peninsula).
Man.	Manitoba Hydro	Kettle Rapids (1970)	1224*	Nelson	130.2	(91.0)	5	(10)	Central Manitoba. First of proposed series of dams on Nelson River. 1.1 sq. miles of forebay area cleared, rest uncleared before flooding.
"	"	Missi Falls (1975)	0	Churchill	200	380		(2)	Northern Manitoba. Diversion of Churchill River (30,000 cfs) via Rat and Burntwood rivers to power projects on Nelson River. Channel route cleared of timber, clearing for site preparation and construction activities completed. Diversion expands natural lake, inundating large surrounding area plus lands adjoining diversion route. Notigi Control regulates diversion.
"	"	Notigi Central (1975)	0	Rat, Churchill		(158)	0	(5)	

TABLE A 1—*continued*

Province	Utility or company	Project (first power)	Capacity (*MW*)	River(s) dammed or diverted	Reservoir area (*sq. miles*) total	(flooded)	Annual drawdown (*ft*) average	(max)	Comments
Man.	Manitoba Hydro	Long Spruce (1977)	1000*	Nelson	9.2	(8.0)	2	(4)	Northeastern Manitoba. Completely cleared before flooding.
"	"	Grand Rapids (1965)	437	Saskatchewan	Cedar Lake 1349	(530)	8.4	(13)	Central Manitoba. Expanded area of existing lake by 65%. 20.2 sq. miles of forebay cleared, rest uncleared before flooding.
"	"	Kelsey (1960)	236	Nelson	273.3	(47.9)	2.1	(10.4)	Northeastern Manitoba. Less than 0.1 sq. mile of forebay cleared, rest uncleared before flooding.
"	"	Jenpeg (1976)	168	Nelson	West Nelson Channel NA	(29.3)	2.5	(4.0)	Central Manitoba. Flow regulation also affects Lake Winnipeg and Outlet Lake, but flooding confined to West Nelson Channel. 19.3 sq. miles of forebay cleared.
"	"	Seven Sisters (1931)	150	Winnipeg	8.0	(3.2)	2.1	(4.4)	Southern Manitoba. Approx. 2.3 sq. miles of forebay estimated cleared.
"	"	Great Falls (1923)	132	Winnipeg	3.6	(1.6)	3.5	(6.4)	Southern Manitoba. Approximately 1.4 sq. miles of forebay estimated cleared.
Sask.	Churchill River Power Co.	Island Falls (1930)	107	Churchill Reindeer	12.5 Reindeer Lake Storage: 1950	(6.25) (NA)	3 2	(5) (8)	Northeastern Saskatchewan. Island Falls headpond cleared only within sight of powerhouse. Reindeer Lake raised 6.5 ft for upstream storage, Negligible flooding, no clearing.
"	Saskatchewan Power Corp.	Squaw Falls (1963)	280	Saskatchewan	Tobon Lake 116	(95)	8	(10)	Northeastern Saskatchewan. Merchantable timber removed. Other tree growth cut, but attempted burning unsuccessful, and floating material requires continuous removal. Flooded area included 33 sq. miles cultivated land.
"	"	Coteau Creek (Gardiner Dam) (1968)	187	South Saskatchewan	Lake Diefenbaker 166	(72)	37	(37)	Southwestern Saskatchewan. Completely cleared of trees and brush before filling. Partial diversion (390 cfs) to Qu'Appelle River Valley.
Alta.	Calgary Power Ltd.	Big Bend (1965)	306	Brazeau	Brazeau Reservoir 17.5	(>16)	55	(60)	West–central Alberta. Owned by Province of Alberta but operated by Calgary Power for power and downstream winter flow augmentation. Basin not cleared prior to flooding. Cleanup in progress by Province of Alberta. Ten-mile power canal inundates additional area.
"	"	Bighorn	108	North Saskatchewan	Bighorn Reservoir (Lake Abraham) 21.5	(>20)	110	(125)	West–central Alberta (foothills). Operated both for power and downstream flow regulation. Basin completely cleared before flooding. Cleanup of driftwood continues.

TABLE A 1—*continued*

Province	Utility or company	Project (first power)	Capacity (*MW*)	River(s) dammed or diverted	Reservoir area (*sq. miles*) total (flooded)		Annual drawdown (*ft*) average (max)		Comments
B.C.	Aluminum Company of Canada	Kemano (Kenney Dam) (1954)	813	Nechako	Ootsa Lake NA	(175)	6.5	(17)	West–central B.C. (Tweedsmuir Park). Diversion of Nechako River drainage through tunnel to Kemano River. Flows decreased in Nechako, increased in Kemano. Inundated "Great Circle" of six lakes and connecting rivers. No clearing before flooding. Underwater cutting of some merchantable timber in progress.
"	Cominco Ltd.	Waneta (1954)	293	Pend d'Oreille	0.55	(0.26)	0	(18)	Southeastern B.C. (West Kootenay). Run-of-river plant. Completely cleared before flooding. Reservoir level may fluctuate rapidly according to power demand.
"	"	Brilliant (1944)	109	Kootenay	1.7	(0.91)	0	(6)	Southeastern B.C. (West Kootenay). Run-of-river plant with upstream flow regulation by Corra Linn Dam at outlet of Kootenay Lake. Water level fluctuates rapidly according to demand. Cleared of timber before flooding.
"	B.C. Hydro	Mica Creek (1976)	2610*	Columbia	172	(164)	NA	(155)	East–central B.C. (Rocky Mountain Trench). Inundates approx. 280 miles of Columbia, Canoe, Wood, Bush, and other rivers. Complete clearing of upper 95 ft of reservoir basin in progress, merchantable timber removed from lower basin. Floating debris will be boomed and burned.
"	Associated Columbia River Treaty Reservoirs	Libby	Powerhouse in Montana USA	Kootenay	Lake Koocanusa 27.9	(21.9)	120	(172)	Southeastern B.C. (East Kootenay). Dam at Libby, Montana will produce 840 MW. At maximum drawdown of 172 ft, reservoir retreats into USA. Maximum drawdown within Canada is 150 ft. Completely cleared prior to flooding. Floating debris is being beached and burned.
"	"	Duncan (1967)	Storage Reservoir	Duncan	Duncan Lake NA	(11.1)	92	(92)	Southeastern B.C. (West Kootenay). Originally cleared for 5 miles above dam. Subsequent clearing continues during drawdown periods.
"	"	Arrow (H. L. Keenleyside) (1968)	Storage Reservoir	Columbia (Arrow Lakes)	Arrow Lakes NA	(39.9)	66	(76)	South–central B.C. Raised elevation of existing lakes. Completely cleared before flooding, stump removal in progress during drawdown periods.
"	B.C. Hydro	G. M. Shrum (W. A. C. Bennett Dam) (1968)	2116	Peace	Williston Lake NA	(650)	65	(105)	Northeastern B.C. (Rocky Mountain Trench). Inundates over 250 miles of Peace, Finlay, Parsnip, Omineca, Ingenika, Ospika, Manson, Nation, and other rivers. Drawdown range cleared for 12 miles above dam, rest uncleared. Floating debris boomed and burned on continuing basis.

TABLE A 1—*concluded*

Province	Utility or company	Project (first power)	Capacity (*MW*)	River(s) dammed or diverted	Reservoir area (*sq. miles*) total (flooded)		Annual drawdown (*ft*) average (max)		Comments
B.C.	B.C. Hydro	Peace Site 1 (1979)	700*	Peace	3.13	(1.56)	1	(5)	Northeastern B.C. (Peace River District) Reservoir basin will be completely cleared before flooding. Run-of-river project with regulation provided by Bennett Dam upstream. First hydro project in B.C. for which environmental impact report completed before construction begun.
"	"	Seven Mile (1979)	700*	Pend d'Oreille	1.36	(0.70)	NA	(5)	Southeastern B.C. (West Kootenay). Reservoir basin will be completely cleared before flooding and managed for recreational use as well as power production. Run-of-river project subject to daily water level fluctuations. Regulation by a boundary plant upstream in USA. Environmental impact report completed before construction begun.
"	"	Kootenay Canal (1975)	500*	Kootenay	NA	(NA)	0	(0)	Southeastern B.C. (West Kootenay). Excavated canal, so cleared before flooding. Run-of-river so no drawdown. Negligible area flooded.
"	"	Bridge River no. 1 and 2 (Terzaghi Dam) (1948)	428	Bridge	Carpenter Lake NA	(17.4)	NA	(32)	West–central B.C. (Bridge River District). No clearing before flooding. Clearing of reservoir margins is proceeding during drawdown periods. Floating debris boomed and burned.
"	"	Jordan River (1971)	150	Jordan	Bear and Elliot lakes NA	(0.94)	30	(60)	Southern Vancouver Island. No clearing before flooding. Reservoir will be completely cleared.
"	"	Cheakamus (1957)	140	Cheakamus	Daisy Lake NA	(0.25)	NA	(30)	Southwestern B.C. (Garibaldi). Completely cleared prior to flooding. Diversion through tunnel to penstocks on Squamish River.
"	"	John Hart (1947)	120	Campbell	NA	(0.98)	2	(3)	Northern Vancouver Island. Cleared prior to flooding. Associated with two upstream projects, including Strathcona which floods 12.5 sq. miles (cleared to ground level before flooding).
"	"	Ruskin (1930)	106	Stave	Hayward Lake NA	(0.86)	2	(3)	Southwestern B.C. (Fraser Valley). Not cleared. Associated with Stave Falls development and Stave Lake. (Not cleared before flooding — underwater clearing in progress.)

Parasites of freshwater fishes — a review of their control and treatment.

Glenn L. Hoffman and Fred P. Meyer. T. F. H. Publications, Inc., Neptune, New Jersey. 224 p. $12.95.

This paperback is another in the series of books on diseases and parasites of fishes published in recent years by T. F. H. Publications. The abbreviated title on front and back covers and on the spine — "Parasites of freshwater fishes" — belies its contents. The full title appears only on the title page (page 1).

Instead of a general treatise on freshwater fish parasites, as would be expected from the cover title, this book provides a summation, mainly in 14 tables, of information on treatment and control of parasitic, including fungal, diseases of freshwater fishes. The sources of information, drawn mainly from literature published through 1970, are indicated in the tables. Generally, the literature has been well covered but some important east European papers published between 1965 and 1970 have been overlooked. These include papers on treatment of cestodoses (*Bothriocephalus*) and nematodoses (*Philometra*) of carp and of *Rhaphidascaris acus* infections. Each table, the longest of which covers 29 pages, is concerned with a different group of organisms: fungi on eggs, fungi on fish, internal protozoans, external protozoans, coelenterates, monogeneans, digeneans, cestodes, nematodes, acanthocephalans, leeches, copepods, turbellarians, and molluscs. A synopsis of the most widely used therapeutic and control methods precedes the tables.

There are two additional tables, one listing data on toxicity to fish of chemical compounds used in treatment of parasitic diseases and one on chemical names and synonyms. Unfortunately the Anthelmintic Index by Janina H. Bard (1972. Tech. Communication No. 43. Commonwealth Inst. Helminthol., St. Albans, England) was not included as a source of information on chemical names, presumably because it was published after 1970.

An index to names of compounds occurring in the tables appears early in the book, rather than at the end, as do useful conversion tables to assist in determining quantities of chemicals required to achieve recommended concentrations. The extensive bibliography of almost 400 entries occupies the final 23 pages.

Interspersed among the 114 pages of tables are 56 pages of unnumbered photographic illustrations, almost all in color, of parasites and diseased tissues, organs or whole fish with parasites in situ. The purpose of including these illustrations is nowhere stated, but if intended to aid the diagnostician many fall short of the mark. Perhaps they were added to make the book more attractive but to this reviewer they have done little except to increase unnecessarily the cost of production of what otherwise is an extremely useful book.

Drs Hoffman and Meyer are to be commended for their labors in compiling and summarizing such a large amount of information from scattered and often obscure sources. Fish pathobiologists and others concerned with treatment and control of fish diseases will find their task made easier by the wealth of data amassed in this book.

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ADDITIONAL PUBLICATIONS/PUBLICATIONS ADDITIONNELLES

The Service also publishes a series of *Bulletins*, each on a specific topic. These are for sale by Information Canada, Ottawa, and remittances must be in advance, payable in Canadian funds to the order of the Receiver General of Canada. *Bulletins* are also available from local booksellers and Information Canada bookshops throughout Canada.

The *Annual Report* of the Board and the biennial *Review* of investigations are available free, on request. All publications may be referred to at establishments located at: Ottawa, Ont.; Nanaimo, Vancouver, and West Vancouver, B.C.; Winnipeg, Man.; Ste. Anne de Bellevue, Que.; St. Andrews, N.B.; Halifax and Dartmouth, N.S.; and St. John's, Nfld.

Le Service publie également une série de *Bulletins*, chacun traitant sur un sujet spécifique. Les publications de l'ORP sont vendues par Information Canada à Ottawa. Les remises, payables d'avance en monnaie canadienne, doivent être établies à l'ordre du Receveur général du Canada. Les *Bulletins* sont aussi en vente chez votre libraire et dans les libraries d'Information Canada.

Vous pouvez obtenir le Rapport Annuel et la Revue biennale gratuitement. On peut consulter ces ouvrages aux établissements situés à Ottawa (Ont.), à Nanaïmo, à Vancouver, et à Vancouver Ouest (C.-B.), à Winnipeg (Man.), à Ste-Anne-de-Bellevue (P.Q.), à St-Andrews (N.-B.), à Halifax et à Dartmouth (N.-E.), et à St-Jean (T.-N.).

Journal of the Fisheries Research Board of Canada

Guide for Authors

A more detailed guide on preparation of manuscripts from theses is available from the Office of the Editor.

Content

We invite submission of manuscripts in the broad field of fisheries management, ocean science, and aquatic environments relevant to Canada.

Articles: Reports of research studies of broad scope that are original contributions to science.

Notes: Differ from papers on the basis of scope or completeness, rather than quality of research. They may be on problems with narrow, readily defined limits; on work that is largely confirmatory; on methodology or research techniques; on advances in knowledge arising as by-products of broader studies; on progress in projects that were discontinued; or on preliminary findings that warrant publication before problems are resolved. They may be organized with as much flexibility as articles except that they have no centered headings and should occupy no more than four printed pages.

Reviews: Detailed articles that are critical appraisals of broad areas of investigation, particularly in fields that have shown rapid development in recent years.

Perspectives: Essays of opinion or hypothesis on fisheries, ocean science, aquatic environments, or related topics that are of concern to the professional and layman. References are desirable; informal style is welcomed.

Letters: Opinion on topics recently under discussion in the *Journal*; preferred maximum length, 500 words. The Editor reserves the right to shorten letters and to make other changes to accord with the style of the *Journal*.

Editorial Practices

The *Style Manual for Biological Journals* (3rd ed. American Institute of Biological Sciences, 3900 Wisconsin Ave. NW., Washington, D.C.) is used as the authority in matters of form. The standards for spelling are: *Webster's Third New International Dictionary* and *le Grand Larousse Encyclopédique*. Titles of periodicals are abbreviated as in the *Biological Abstracts* list. References to literature are made by the name-and-year system. The *Journal* follows the names and spelling recommended in *A List of Common and Scientific Names of Fishes from the United States and Canada* (Third Edition, 1970) Special Publication No. 6 of the American Fisheries Society.

Series titles should be avoided. An *abstract* is required for all manuscripts, and should state concisely, in less than 250 words, what was done, the essentials of the new knowledge, and the main conclusions. Abstracts are published in English and French; those submitted in one language only are translated by the *Journal*.

The Editor normally submits each manuscript to at least two *referees*. Contributors are encouraged to suggest at least four names to be added to the list from which referees may be selected.

Illustrations should be submitted in triplicate as photographs (*glossy prints*) no larger than a standard page and must accompany the manuscript. Prints should not be mounted, stapled, or clipped. Symbols, letters and numerals must be neat, and at least 1.5 mm high when the illustration is reduced to the appropriate size. Drawings should, when possible, be grouped to facilitate comparisons.

Proofs are sent to the author, who is responsible for correcting only errors in typesetting. *Alterations to the content must be avoided.*

Fifty *reprints* are supplied free. Additional reprints may be purchased at the time of publication (an order form is sent out with the galley proof). All orders should be sent to the Printing Department, University of Toronto Press, 5201 Dufferin Street, Downsview, Ont. M3H 5T8. Invoices relating to the reprints will be sent out by the Printer. A charge of $30.00 per page is made for articles published. When submitting a manuscript, an author should state that his institution will accept this charge.

Checklist on Manuscripts

Attention to the following questions will expedite appraisal of manuscripts by referees and editors.

Are the findings, interpretations, and conclusions adequately documented and relevant to the purpose of the study?

Are all the tables and figures needed, and organized to facilitate comparisons? Are there inconsistencies between tables or figures and the text, or within the text? Should some of the data be made available separately, in a manuscript report or at a data repository? If you use statistical analysis are the statistics subordinate to the research?

Would any of the text be clearer if condensed? Are summary statements given at the beginning of sections and paragraphs, and are details in sections and paragraphs relevant to their topics? Does the organization of the manuscript follow logically from the statement of purpose in the introduction?

Does the *title* encompass the content of the report?

Does the *abstract* give the essentials of the new knowledge?

Is the *introduction* largely limited to the scope, purpose, and rationale of the study? Is review of the literature limited to defining the problem?

Are details of *materials and methods* limited to what scientists need in understanding the design of the study and in judging adequacy of the data?

Are generalizations on the *results* adequate? Are findings distinguished from inferences from them?

Is *discussion* limited to interpretation and significance of the findings?

Journal de l'office des recherches sur les pêcheries du Canada

Guide des Auteurs

On peut se procurer au bureau du Directeur de la publication un guide plus détaillé pour la préparation de manuscrits à partir de thèses.

Sujets

Nous désirons recevoir des manuscrits s'insérant dans le vaste domaine de la gestion des pêches, des sciences de la mer et des milieux aquatiques au Canada.

Articles: Comptes rendus d'études d'une portée générale, constituant des contributions inédites à la science.

Notes: Se distinguent des articles par la portée et le degré d'achèvement plutôt que par la qualité des recherches. Elles peuvent traiter de problèmes particuliers et bien définis; de travaux qui sont en grande partie confirmatoires; de méthodologie ou de techniques de recherche; de progrès de la connaissance découlant d'études plus vastes; de développements dans des projets abandonnés; ou de découvertes préliminaires qui méritent d'être publiées avant la solution de problèmes à l'étude. Les notes peuvent être présentées d'une façon aussi souple que les articles, mais elles ne doivent pas porter d'en-têtes centrés ni occuper plus de quatre pages.

Critiques: Articles détaillés constituant une appréciation critique de vastes champs de recherches, particulièrement dans les domaines ayant connu de rapides progrès au cours des dernières années.

Perspectives: Essais de l'opinion ou de l'hypothèses sur les pêches, les sciences de la mer, les milieux aquatiques, ou sur des sujets connexes qui intéressent professionnels et profanes. Il est préférable de donner des références et d'écrire, si possible, dans un style simple.

Lettres: Opinions sur des sujets exposés dans le *Journal*. Longueur maximale préférable: 500 mots. Le directeur se réserve le droit le raccourcir les lettres et de faire d'autres modifications dans le style du *Journal*.

Dispositions générales

Le *Style Manual for Biological Journals* (3e éd., publié par l'American Institute of Biological Sciences, 3900 avenue Wisconsin N.O., Washington, D.C.) sert de guide quant à la forme de présentation. Le *Webster's Third New International Dictionary* et le *Grand Larousse Encyclopédique* font autorité pour l'orthographe des mots. Les titres de périodiques sont abrégés suivant les *Biological Abstracts*. Les références bibliographiques dans le texte doivent suivre le système nom de l'auteur-année. Pour les noms de poissons et leur orthographe, le *Journal* suit les recommandations contenues dans *A List of Common and Scientific Names of Fishes from the United States and Canada* (Troisième édition, 1970), Publication spéciale No. 6 de l'American Fisheries Society.

Il faut éviter les *articles en série*. Un *résumé* doit accompagner chaque texte et doit exposer brièvement (moins de 250 mots) le travail accompli, les points essentiels des connaissances acquises et les principales conclusions. Les résumés paraissent en anglais et en français, le *Journal* veillant à la traduction dans le cas des présentations unilingues.

Le directeur soumet d'ordinaire chaque texte à l'approbation de deux *arbitres* ou plus. Nous encourageons les collaborateurs à suggérer au moins quatre personnes dont les noms pourraient figurer sur la liste des arbitres.

Les *illustrations* doivent être sous forme de photos (*sur papier glacé*), ne pas dépasser les dimensions d'une page normale et accompagner le texte. Elles ne doivent pas être montées, coupées ni brochées. Les symboles, lettres ou chiffres doivent se détacher avec précision et avoir au moins 1,5 mm de hauter lorsque l'illustration est réduite à la grandeur voulue. Les dessins doivent, autant que possible, être groupés pour faciliter l'étude comparative.

L'auteur doit revoir les *épreuves* qu'on lui remet et en corriger seulement les erreurs typographiques. *Il doit éviter de changer le contenu du texte.*

Cinquante *tirés à part* sont fournis gratuitement. Les tirés à part peuvent être achetés au moment de la publication. Un bon de commande à cet effet accompagne les épreuves; il doit être retourné en même temps que celles-ci, non pas au bureau de la rédaction, mais au Printing Department, University of Toronto Press, 5201 Dufferin Street, Downsview, Ont. M3H 5T8, qui se chargera de la facturer. Les frais sont de $30.00 par page pour la publication des articles. Quand un auteur soumet un manuscrit, il doit spécifier que son institution accepte les frais.

Listes de contrôles pour manuscrits

Une attention particulière aux questions suivantes facilitera l'évaluation des manuscrits par les arbitres et les éditeurs.

Les découvertes, interprétations et conclusions sont-elles bien documentées et pertinentes au but de l'étude?

Les tableaux et figures sont-ils tous nécessaires et agencés pour faciliter les comparaisons? Y a-t-il contradiction entre les tableaux ou les figures et le texte, ou dans le texte même? Est-ce que certaines données devraient être présentées séparément, dans un rapport manuscrit ou dans un dépôt de données? Si vous faites une analyse statistique, la statistique cède-t-elle le pas à la biologie?

Le texte y gagnerait-il en clarté s'il était plus condensé, en tout ou en partie? Contient-il des exposés sommaires au début de chaque section ou paragraphe, et les détails de ces sections et paragraphs son-ils pertinents au sujet traité? La marche du manuscrit est-elle conforme à la logique énoncée dans l'introduction?

Le *titre* est-il concis, tout en étant représentatif du contenu du rapport?

Le *résumé* donne-t-il l'essentiel des connaissances nouvelles?

L'*introduction* se limite-t-elle à une esquisse de la portée, du but et des raisons de l'étude? La revue de la littérature se limite-t-elle à la définition du problème?

La section *matériel et méthode* contient-elle le minimum de détails qui permettront aux autres scientifiques de saisir les grandes lignes de l'étude et de juger de la valeur des données?

Les généralisations sur les *résultats* sont-elles adéquates? Permettent-elles de distinguer entre constatations et déductions?

La *discussion* est-elle limitée à l'interprétation et à l'évaluation des découvertes?

Journal of the Fisheries Research Board of Canada

Guide for Typists Preparing Copy

Read "Guide to Authors" in the current volume of the *Journal*. When in doubt about how to type or arrange details, follow *Journal* practice.

Type the manuscript on white bond paper, not flimsy, preferably size 21.5 × 28 cm (8.5 × 11 inches). If possible, use paper with the lines numbered in the margin. Leave all margins at least 2.5 cm wide.

Double-space all parts of the manuscript, including tables, captions for illustrations, footnotes, and the reference list. Underline only material that is to be printed in italics. Indent the first line of each paragraph in the text and of each footnote.

In titles and headings, capitalize only the first word and proper names and adjectives. For small capitals, use small letters.

Indicate all text footnotes by superscript arabic numerals. Number them consecutively throughout the manuscript, starting with those on the title page. Place each footnote immediately below the reference to it, separating it from the text by horizontal lines.

On the first page type only the title, the authors' names and affiliations, related footnotes, and the running head (see Appendix A). Type the abstract on a separate page (see Appendix B). Number all pages, beginning with the title page and including those for tables and captions for illustrations.

Have the author check the finished manuscript, and send the ribbon copy and two other clear copies to the Office of the Editor.

Tables: Examine the current volume of the *Journal* to see how tables are set up (see Appendix C).

Note especially the following concerning *numbered tables:*

Type each on a separate page, using paper without the lines numbered.

Number them with arabic numerals.

Use horizontal lines above and below the headings and below the columns, and seldom elsewhere. Never use vertical lines; leave extra spaces instead.

Indicate table footnotes by superscript small letters and type them below the table.

Place the tables after the list of references.

Where each table is first referred to, type in the margin "Table — near here."

Note that *text tables* are not numbered, are typed with the text, and seldom need horizontal lines (see Appendix C).

Illustrations: Send at least 3 *glossy prints* (no larger than 21.5 × 28 cm) of each illustration with the manuscript. Type the author's name and figure number on a strip of paper and fasten it to the back of the print. Do not write or type on the print itself. Also, type the captions in succession on a separate page, headed "Captions for illustrations." Put this page at the end of the manuscript.

Where each figure is first referred to, type in the margin "Fig. — near here."

Mathematical Expressions, Equations, and Formulas: Leave three spaces above and below lines that have much material in superscripts, and above and below equations and formulas. In the various expressions, place each component in its correct position (see Appendix D).

Show all symbols clearly. In the margin, spell out Greek letters the first time they occur, and distinguish between the small letter *l* and the numeral *one*, and between the capital letter *O* and the numeral *zero*. Make other explanatory notes similarly.

References: Check the text to see that all references in the list are referred to. Type the reference list, double-spaced, in the style used in the *Journal* (see Appendix E). Names of journals are abbreviated as in the *Biological Abstracts* list; if an abbreviation is in doubt, type the name in full.

Spellings: About 100 words common in fisheries journals are listed in Appendix F.

Appendices: Appendices A to F are available on request from the Office of the Editor.

Journal de l'office des recherches sur les pêcheries du Canada

Guide pour les secrétaires d'auteurs

Lisez le "Guide des Auteurs" reproduit dans l'édition courante du *Journal*. Si vous avez des doutes sur la façon de dactylographier le texte ou d'en agencer les détails, suivez la pratique du *Journal*.

Dactylographiez le manuscrit sur papier blanc de bonne qualité, et non sur papier pelure, mesurant de préférence 21.5 × 28 cm (8.5 × 11 pouces), laissant toujours une marge d'au moins 2.5 cm. Si possible, employez un papier avec lignes numérotées en marge.

Tout le manuscrit, y compris tableaux, légendes de figures, renvois et références bibliographiques, devra être dactylographié à double interligne. Ne soulignez que les mots qui devront être imprimés en italique. Mettez en retrait la première ligne de chaque paragraphe du texte et de chaque renvoi.

Dans les titres et les en-têtes, n'employez la majuscule que pour le premier mot et les noms propres. Pour les petites majuscules, employez les miniscules du dactylographe.

Indiquez tous les renvois du texte par des chiffres arabes suscrits. Numérotez les renvois consécutivement par tout le texte, à commencer par ceux de la page titre. Placez chaque renvoi directement sous sa référence, le séparant du texte par des lignes horizontales.

La première page ne doit contenir que le titre de la publication, le nom et l'affiliation de ou des auteurs, les renvois appropriés et le titre courant (voir Appendice A). Dactylographiez le résumé sur une page séparée (voir Appendice B). Numérotez chaque page, à commencer par la page titre, et y compris celles qui contiennent les tableaux et la légende des figures.

Voyez à ce que l'auteur vérifie le manuscrit final, et soumettez la première copie et ainsi que deux copies lisibles au bureau du Directeur de la publication.

Tableaux. Consultez une copie du *Journal* pour la composition des tableaux (voir Appendice C).

Portez une attention particulière à ce qui suit au sujet des *tableaux numérotés*.

Dactylographiez chaque tableau sur feuille séparée, vous servant de papier sans lignes numérotées.

Numérotez les tableaux en chiffres arabes.

Tracez des lignes horizontales au-dessus et au-dessous des en-têtes et au-dessous des colonnes, rarement ailleurs; ne tracez jamais de lignes verticales; laissez plutôt des espaces supplémentaires.

Indiquez les renvois dans les tableaux par les minuscules suscrites et placez les renvois au bas du tableau.

Placez les tableaux à la suite des références bibliographiques.

A l'endroit où le tableau est mentionné pour la première fois, indiquez dans la marge "Tableau — près d'ici."

Remarquez que les *tableaux dans le texte* ne sont pas numérotés, sont dactylographiés avec le texte et ne requièrent que rarement des lignes horizontales (voir Appendice C).

Figures: Envoyez avec le manuscrit trois photos *sur papier glacé* (21,5 × 28 cm ou moins) pour chaque illustration. Dactylographiez le nom de l'auteur et le numéro de la figure sur une lisière de papier que vous collerez au dos. N'écrivez pas à la main ou à la machine sur la photographie même. En plus, dactylographiez les légendes, dans l'ordre, sur feuille séparée, intitulée "Légendes des figures." Intercalez cette feuille à la suite du texte.

A l'endroit où chaque figure est mentionnée pour la première fois, inscrivez en marge "Fig. — près d'ici."

Equations, formules et expressions mathématiques: Laissez trois espaces au-dessus et au-dessous des lignes renfermant des chiffres ou des lettres suscrits et souscrits, ou encore au-dessus et au-dessous d'équations et de formules. Placez chaque composante des différentes expressions dans la position qui lui est propre (voir Appendice D).

Indiquez clairement tous les symboles. Epelez en marge les lettres grecques, la première fois qu'elles apparaissent. Faites une distinction entre la lettre *l* et le chiffre *un*, et entre la majuscule *O* et le chiffre *zéro*. Insérez de la même façon toute autre note explicative.

Références: Vérifiez le texte afin de vous assurer que toutes les références apparaissant dans la liste bibliographique sont bien mentionnées dans le texte. Dactylographiez à double interligne dans le style en usage dans le *Journal* (voir Appendice E). Les noms de revues sont abrégés suivants les *Biological Abstracts*; en cas de doute, écrivez le nom au long.

Orthographe: Une liste d'environ 100 mots communément employés dans les périodiques sur les pêches est donnée en Appendice F.

Appendices: On peut se procurer une copie des Appendices A à F sur demande au bureau du Directeur de la publication.

NOAA Offers New Service in Technical Information

A new service known as OASIS (Oceanic and Atmospheric Scientific Information System) has been announced by the Technical Information Division (TID) of the National Oceanic and Atmospheric Administration.

The service offers computer searches of citations to published literature and references to research in progress or recently completed in the fields of atmospheric, marine, and earth sciences and marine resources. Data bases that can be searched by making a request to the TID include both NOAA and non-NOAA bibliographic files. Current awareness (periodic search for new information) as well as one-time retrospective searches (everything available to date) are offered.

Inquiries about OASIS services should be directed to:

Technical Information Division
NOAA
Washington, D.C. 20235, USA
(tel. 202–343–6454)

Nouveau service d'information technique à la NOAA

La Technical Information Division (TID) de la National Oceanic and Atmospheric Administration a annoncé la mise sur pied d'un nouveau service qui s'appelle OASIS (Oceanic and Atmospheric Scientific Information System).

Ce service fait des recherches mécanographiques concernant des citations d'ouvrages publiés et des références à la recherche en cours ou récemment terminée dans les domaines des sciences atmosphériques, marines et de la terre et des ressources marines. Les bases de données sur lesquelles on peut demander des renseignements en faisant la demande à la TID comprennent les fiches bibliographiques de la NOAA et de certains autres organismes. On peut vous renseigner sur des données actuelles (recherche périodique pour obtenir de nouveaux renseignements) ou faire une recherche unique de rétrospection (pour obtenir tous les renseignements disponibles à ce jour).

Les demandes de renseignements sur le service OASIS doivent être envoyées à la:

Technical Information Division
NOAA
Washington, D.C. 20235, USA
(tél. 202–343–6454)

Translation Series

McTaggart-Cowan, G. I. (Compiler and editor.) 1974. Author–subject index to Fisheries Research Board of Canada Translation Series Nos. 1–1600. Marine Sciences Research Laboratory Technical Reports No. 8: 238 p.

($5.00)

Available from:

Marine Sciences Research Laboratory
Memorial University of Newfoundland
St. John's, Newfoundland

Lists of articles in the Translation Series from 1601–2825, with indexes to authors and translators, are available free from:

Department of the Environment
Fisheries and Marine Service
Office of the Editor
116 Lisgar St.,
Ottawa, Ont. K1A 0H3

Photocopies of the translations are available at 10¢ per page (minimum $1.00) from:

Translation Services
Canada Institute for Scientific and Technical Information
National Research Council of Canada
Ottawa, Ont. K1A 0S2

Traductions

McTaggart-Cowan, G. I. (compilateur et éditeur) 1974. Index par auteur et sujet des Traductions nos 1 à 1,600 de l'Office des recherches sur les pêcheries du Canada. Rapports techniques du Laboratoire de recherche en sciences de la mer, no 8, 238 p.

($5.00)

Offert au:

Laboratoire de recherche en sciences de la mer
Université Memorial de Terre-Neuve
Saint-Jean (Terre-Neuve)

On peut se procurer gratuitement la liste des articles de la série Traductions, de 1,601 à 2,825, avec index des auteurs et traducteurs, à l'adresse suivante:

Ministère de l'Environnement
Service de pêches et des sciences de la mer
Bureau du directeur d la publication
116, rue Lisgar
Ottawa (Ont.) K1A 0H3

On peut se procurer à 10¢ la page (minimum de $1.00) des photocopies des traductions à l'adresse suivante:

Services de traduction
Institut canadien de l'information scientifique et technique
Conseil national de recherches du Canada
Ottawa (Ont.) K1A 0S2

Journal of the Fisheries Research Board of Canada

Journal de l'office des recherches sur les pêcheries du Canada

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